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The front cover shows an installation consisting of four 5138 type "I.C." multi-wash collectors at the Consett Iron Co. Ltd. Each unit will handle 42,000 cfm of dust-laden air. (Photo by courtesy W. C. Holmes Ltd., Huddersfield.)

Classified Advertisements, after page 538

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B.C.E., 5, 8, 542. U.D.C. No. 66.074.

ÉPURATION DES GAZ INDUSTRIELS

par le Dr. N. Pilpel

L'article présente une revue des appareils dont on dispose actuellement pour extraire et arrêter la poussière et définit le champ d'action de chaque appareil. L'auteur étudie, en particulier, les électroprécipitateurs, les agglomérateurs soniques ou mécaniques, les séparateurs à inertie et les appareils qui combinent plusieurs systèmes. Il donne également des renseignements sur les appareils offerts dans le commerce et leur prix.

Kurzreferate

B.C.E., 5, 8, 542. U.D.C. No. 66.074.

INDUSTRIELLE GASREINIGUNG

von Dr. N. Pilpel

Eine Übersicht über die verfügbaren Typen von Staubseparatoren und -Extraktoren und die Arbeitsgebiete dieser Typen. Die besprochenen Einrichtungen umfassen Elektropräzipitatoren, Sammler sonischer oder mechanischer Bauart, Trägheitsseparatoren und Kombinationen dieser Typen. Der Artikel enthält auch einige Bemerkungen über die Wahl der Einrichtungen und ihre Gestehungskosten.

Резюме

B.C.E., 5, 8, 542. U.D.C. No. 66.074.

ОЧИСТКА ПРОМЫШЛЕННЫХ ГАЗОВ

Др. Н. Пилпел

Рассматривается существующее оборудование для отделения и задержки пыли и указывается надлежащая область для каждого типа такого оборудования. Обсуждаются в частности такие различные типы оборудования как электро-фильтры, агломераторы звукового и механического типа, инерционные сепараторы и комбинированные типы оборудования. Есть также заметки о выборе наиболее подходящего оборудования и его стоимости.

B.C.E., 5, 8, 552. U.D.C. No. 66.074.327.

SÉCHAGE DES GAZ PAR ADSORPTION — DEUXIÈME PARTIE

par J. W. Carter

L'auteur examine les caractéristiques des produits siccatifs solides et décrit la performance et les points principaux des sécheuses à lit fixe utilisant ces produits. Cette seconde partie se termine sur des notes portant sur les méthodes de dessin des sécheuses à lit fixe.

B.C.E., 5, 8, 552. U.D.C. No. 66.074.327.

ADSORPTIONSTROCKNUNG VON GASEN, TEIL II

von J. W. Carter

Der Verfasser berücksichtigt die Kennzüge fester Feuchtigkeitsabsorbiermittel und beschreibt die Leistung und Konstruktionszüge von Festbetttrocknern, die solche Trockner verwenden. Der zweite Teil des Artikels schliesst mit Bemerkungen über die Konstruktion derartiger Festbetttrockner.

B.C.E., 5, 8, 552. U.D.C. No. 66.074.327.

ВЫСУШИВАНИЕ ГАЗОВ АДСОРБЦИЕЙ — ЧАСТЬ 2

Ж. В. Картер

Автор статьи рассматривает характерные свойства твердых адсорберов влаги и описывает работу и черты конструкции неподвижной сушильной плиты где используются такие высушивающие средства. В конце второй части статьи поднимается вопрос о методах конструкции неподвижных сушильных плит.

B.C.E., 5, 8, 559. U.D.C. No. 66.045.1-41.

RENDEMENT DES ÉCHANGEURS DE CHALEUR À PLAQUES

Un procédé russe, utilisant un échangeur de chaleur à plateau ondulé, à permis d'obtenir un transfert de chaleur donnant des résultats d'un type rarement présenté dans les revues.

B.C.E., 5, 8, 559. U.D.C. No. 66.045.1-41.

LEISTUNG VON PLATTEN-WÄRMEAUSTAUSCHERN

Wärmeaustauschresultate mit einem russischen Wärmeaustauscher in Form einer Wellplatte geben Konstruktionsdaten, die in der Literatur nur selten zu finden sind.

B.C.E., 5, 8, 559. U.D.C. No. 66.045.1-41.

РАБОЧИЕ КАЧЕСТВА ПЛАСТИНЧАТЫХ ТЕПЛООБМЕННИКОВ

Результаты теплопередачи используя русский процесс применения пластинчатого теплообменника с волнообразными каналами содержат данные конструкции, которые редко встречаются в технической литературе.

B.C.E., 5, 8, 570. U.D.C. No. 66.015:061.3.

SECOND SYMPOSIUM EUROPÉEN SUR LE GÉNIE DE LA RÉACTION CHIMIQUE

Impressions d'une importante conférence organisée en mai dernier, avec résumés des communications présentées.

B.C.E., 5, 8, 570. U.D.C. No. 66.015:061.3.

ZWEITES EUROPÄISCHES SYMPOSIUM ÜBER REAKTIONS-TECHNIK

Eine Übersicht über eine wichtige Konferenz im Mai d.J. mit einer Zusammenfassung der stattgefundenen Vorlesungen.

B.C.E., 5, 8, 570. U.D.C. No. 66.015:061.3.

ВТОРОЙ ЕВРОПЕЙСКИЙ СИМПОЗИУМ ПО ВОПРОСУ РЕАКТОРНОГО ТЕХНОЛОГИИ

Впечатления от важной конференции состоявшейся в мае текущего года и резюме представленных на ней докладов.

B.C.E., 5, 8, 573. U.D.C. No. 66.045.5.

DÉTERMINATION DE LA FORCE D'ENTRAÎNEMENT D'ENTHALPIE DANS LES CALCULS DES TOURS DE REFROIDISSEMENT

On a essayé à plusieurs reprises, par le passé, de formuler une équation de la force d'entraînement pouvant s'appliquer aux calculs des tours de refroidissement. L'article modifie une méthode existante et compare les résultats avec ceux qui sont obtenus par d'autres méthodes.

B.C.E., 5, 8, 573. U.D.C. No. 66.045.5.

BESTIMMUNG DER ENTHALPIE-ANTRIEBSKRAFT IN KÜHLTURM-BERECHNUNGEN

In der Vergangenheit wurden verschiedentlich Versuche unternommen, eine für die Berechnungen von Kühltürmen geeignete Formal der Antriebskraft zu schaffen. Der Artikel stellt eine Änderung einer bestehenden Methode dar und vergleicht das Résultat mit denen anderer Methoden.

B.C.E., 5, 8, 573. U.D.C. No. 66.045.5.

ОПРЕДЕЛЕНИЕ ЭНТАЛЬПИИ ДВИЖУЩЕЙ СИЛЫ ПРИ ВЫЧИСЛЕНИИ БАШЕННЫХ ХОЛОДИЛЬНИКОВ

В прошлом было сделано много попыток получить подходящий вид движущей силы для использования при вычислении башенных холодильников. Статья предлагает изменения в одном из существующих методов и сравнивает полученные результаты с результатами других методов.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

New Heat Exchange Data

BASIC information on heat transfer is being obtained at the National Engineering Laboratory. The aim is to assist engineers in the design of conventional and novel heat-exchange equipment. In progress are investigations of dropwise condensation of steam, heat transfer to regenerator matrices, and heat transfer to fluids flowing through pipes. Over the last few years a comprehensive study has been carried out on the effect of features which disturb the flow, such as bends and abrupt changes of section. Much of the work has been concerned with the effect on the local heat-transfer coefficients of an abrupt change in cross-sectional area of the pipe, using water as the fluid. The rig employed consists of two long, straight lengths of pipe joined end to end. Water flows through the pipes from a constant-head tank; by reversing the direction of the flow the effect of both an abrupt convergence and an abrupt divergence can be studied. The pipe is heated by passing a direct current of up to 5000 amperes through it. The general conclusion* is that, with an abrupt convergence, the heat-transfer coefficient rises immediately after the change of section but falls to the average value a few diameters downstream. With an abrupt divergence the increase in heat-transfer coefficient immediately after the change of section is greater and persists further downstream than with convergent flow. The lower the Reynolds number the greater is the rise in heat-transfer coefficient and the greater is the length travelled before the normal value is reached; similar effects are observed as the ratio of cross-sectional areas is increased. Comparable results were obtained with air.

In another project the performance of a plate heat-exchanger has been investigated with the flow passages in series and in parallel, for a range of temperatures and flow rates. Individual heat-transfer coefficients have been determined from measurements of overall heat transfer, and the pressure drop for various flow conditions has also been measured. A Perspex end-plate has been provided to allow visual study of the flow—particularly the existence of any dead-flow regions. Later it is intended to compare performance with that of other types of heat exchangers.

* Summarised in *Mechanical Engineering Research* 1959. H.M.S.O. 1960. 4s. 6d.

How High is a Chimney?

UNDER the Clean Air Act, it is the responsibility of local authorities to approve the height of new industrial chimneys. They need to be satisfied that the height will be sufficient to prevent, as far as practicable, the smoke, grit, dust or gases from becoming prejudicial to health or a nuisance. This is the only reference in the Act to the control of gaseous emissions.

At a recent meeting of the Institute of Fuel, MR. G. NONHEBEL made some suggestions for both the height of chimneys and the conditions at ground level. A new chimney serving a large plant should be high enough to ensure that the calculated 3-minute maximum concentration of sulphur dioxide at ground level should not exceed 40 parts per hundred million in areas of heavy industry or high housing density and 50 pphm in other areas. Similarly, the calculated maximum rate of deposit of grit and dust from a new chimney should not exceed 1,000 g/100 m^2 month with a wind direction constant within an octant. The formulae proposed were not considered applicable to emissions from relatively low chimneys serving small plants; consequently, recommendations based on experience were made for a sliding scale of heights from 60 to 120 ft for boiler plants of aggregate capacity 5,000 to 33,000 lb/h. Worked examples showed that rate of dust deposit rather than ground-level concentration of SO_2 is usually the factor which should control the height of boiler plant chimneys. Preventing emission of particles or aggregates larger than 76 microns is most important. There are of course other factors which need attention such as the rate of ground coverage by deposited dust and the distance from the chimney at which the dusty plumes become substantially invisible. For the former a limit of 0.04% per day was proposed and for the latter a distance equal to three times the chimney height.

We have been informed that no formal approach was made to any official body before the paper was presented. Neverthless it is noteworthy that MR. NONHEBEL is a member of the Standing Conference of Cooperating Bodies which deals with air pollution and of a further committee considering the height of chimneys. Both are organised under the auspices of D.S.I.R.

The paper has been published in *Smokeless Air* No. 114 (Summer 1960, 2s.) and is due to appear with full discussion in *J. Inst. Fuel.*

"Entrainment" with Inert Gas from Non-Ideal Binary Solution

A LARGE part of the *Transactions* of the Roumanian Institute of Petroleum, Gas and Geology is devoted to chemical processing. In Vol. 5 is a series of papers by I. V. ROBU—who has also contributed to our columns—on mass transfer, differential absorption and chromatography. We also noted a discussion of the inert gas entrainment of volatile components from non-ideal solutions. PROFESSOR ROBU considered the cases of non-ideal solutions with both components volatile and of non-ideal solutions with one component volatile and the other non-volatile. For each of these cases an equation has been derived giving the number of moles of inert gas necessary to reduce the concentration of the more volatile component from its initial value to the final desired value. The derivation is based on assuming a constant rate of flow of inert gas with equilibrium established between the liquid and gas phases at all times. It is an extension of the general equation of entrainment derived in earlier work by the

author for an ideal binary liquid. The equations have been tested by introducing the condition of ideal behaviour. The expression thus obtained coincides with that given in the literature for an ideal binary liquid with one non-volatile component. The paper goes on to discuss the application of these equations to the practical case when the concentration of the volatile component in the mixture of vapour and gas must be kept constant for the entire duration of the entrainment process. This is clearly not possible at a constant total pressure without raising the temperature. The author therefore derives expressions for the variation of temperature as a function of time for the case of ideal and non-ideal, binary liquids.

Analogue and Digital Computing in One System

AUTOMATIC process control is specifically mentioned by Redifon Ltd., as one of the fields of application of their new combined analogue-digital computing system called Radic. At a recent demonstration of the equipment they also illustrated its use in distillation column design.

Basically the system comprises an assembly of direct-current drift-corrected amplifiers, electronic multipliers and diode-network function generators, operating on a relatively fast time scale. These electronic analogue computing elements are backed up by electro-mechanical servo-operated integrators and multipliers. They can be made to add, subtract, multiply and divide, integrate and differentiate with respect to time and generate mathematical functions such as sines, squares or logarithms. Numbers and physical variables are represented in the analogue computing elements by voltage levels. For feeding numerical data in and out of the analogue computing elements, and for storage of data, digital devices are used. Digital storage is provided by a magnetic tape equipment which can also be used for simulating time delays and other special purposes. The combination is claimed to be the first of its kind in the world specifically developed to unite the stability, convenient input/output equipment and extensive storage facilities of the digital machine with the speed of operation, ease of programming and low cost of the analogue. Cost of the system will range from about £10,000 bringing it within the reach of smaller companies or organisations requiring a flexible computing system for carrying out complex calculations, simulation and data reduction.

A special version of the unit is designed to operate as a self-contained, transportable process analyser. In addition to the basic facilities of the computer this will contain multipliers and integrators to allow autocorrelation or cross correlation functions to be computed from analogue data recorded on tapes from the processes which are under investigation.

Solar Energy for Process Purposes?

IN Britain, even in midsummer, it seems like a wry joke to discuss possibilities of using solar energy. Yet for many parts of the world there are real prospects of greatly extending its applications well beyond the traditional salt pans and crude exposed drying of many products. A recent paper by GEORGE O. G. LOF and J. A. DUFFIE of the University of Wisconsin discusses applications in Latin America. There is apparently an excellent example of a solar evaporation process near Mexico City. The *Caracol*, (the snail), is a hugh spiral canal, through which progresses an evaporating solution containing principally Na_2CO_3, $NaHCO_3$ and NaCl. The concentration of the solution entering at the outer edge is about 4% solids. This alkaline, brackish water, and another supply at about 14% solids, are pumped from wells tapping two shallow zones of the nearly dried-up Lake Texcoco. The 14% solution enters nearer the centre, at a point where the concentration has been increased to about that same value. In the centre (exit) of the evaporator, the solution is nearly saturated with $NaHCO_3$, and this solution goes to a plant for conversion to soda ash and caustic soda. Present production is 250 metric tons per day of soda ash and 100 metric tons per day (dry basis) of caustic soda in 40% solution. After removing the alkalies, the mother liquor is returned to the *Caracol* or to solar crystallisation ponds for NaCl production.

The average net daily evaporation of water for a 12 year period, has been 3.10 mm per day, or a net annual evaporation of about 9,500,000 metric tons of water. To evaporate this much water by conventional means would have cost about three million dollars per year; this can be considered a first rough estimate of the annual value of the solar evaporation plant. In addition the authors consider that solar distillation is one of the promising methods for producing potable and process water supplies from sea water or other saline and impure sources.

It should be noted that even in sun-starved Britain, there is work in progress on this subject. On the roof of the Tropical Products Institute are flat plate solar heat collectors for experimental work linked with economic appraisal of possible techniques for tropical countries. At Woolwich Polytechnic there are two projects in progress on solar heating and there are plans for work on this theme at the laboratories of the Heating and Ventilation Research Association.

Careers Booklet

OUTPUT of chemicals today is double that of ten years ago. Few of the larger industries can match this rate of expansion and the Association of British Chemical Manufacturers are well justified in drawing attention to their record in the first few lines of a new illustrated careers booklet.* Pithily they have surveyed this diverse industry, its main groupings and its working conditions. A chart shows possible lines of progress for a young recruit, based on various ages of entry and types of qualification. In general an attempt has been made to provide perspective for young people whether they are likely to enter operative, craftsman and mechanic posts or positions demanding higher qualification. An appendix lists individual firms with their main factories and products, setting out the career opportunities in each. We understand that this is only the second booklet of its kind issued by the Association; when the first went out of print, an entirely new version was prepared.

This is an attractive publication, with emphasis on offering worth-while careers rather than "jobs" and it should succeed in its purpose. May we suggest that in any future revision the authors make the point that the industry has been linked with the growth of the fourth primary technology. Is not this something to fire the imagination of youngsters?

* "The Chemical Industry—A Career for You." A.B.C.M., Strand, London, W.C.2.

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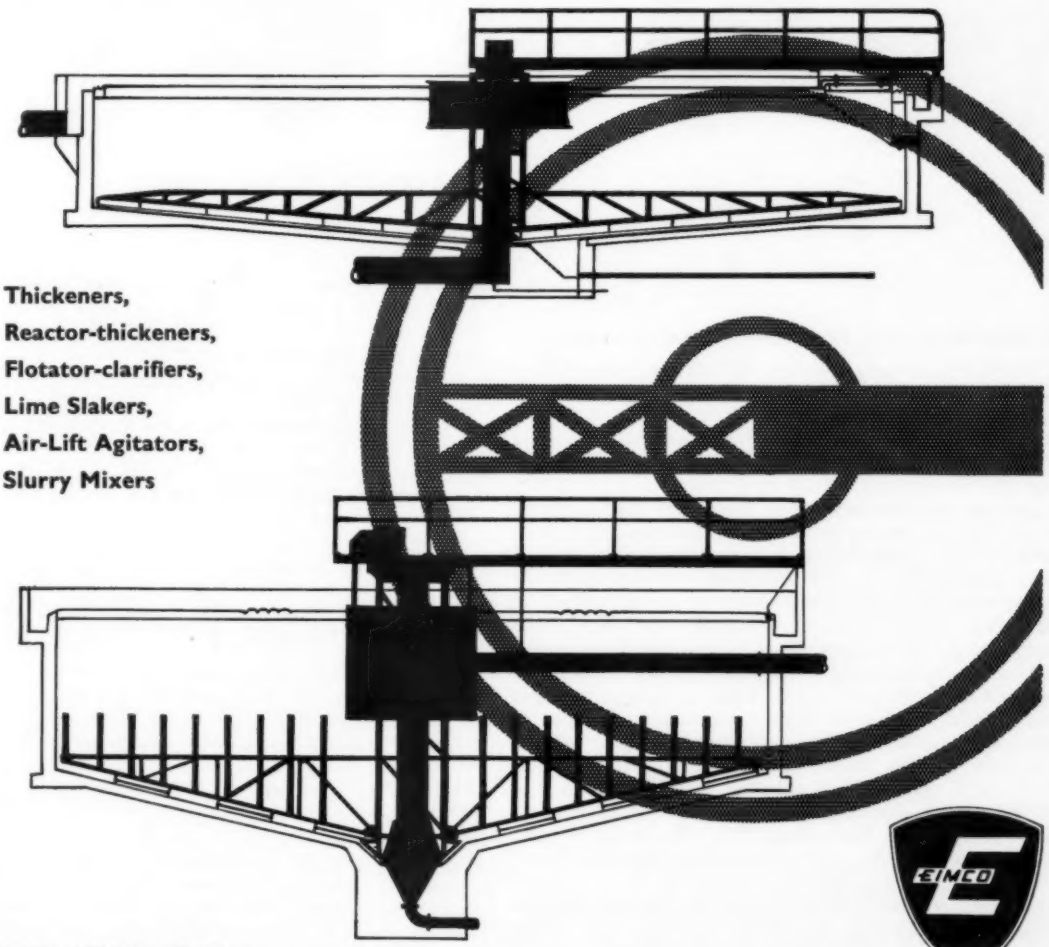

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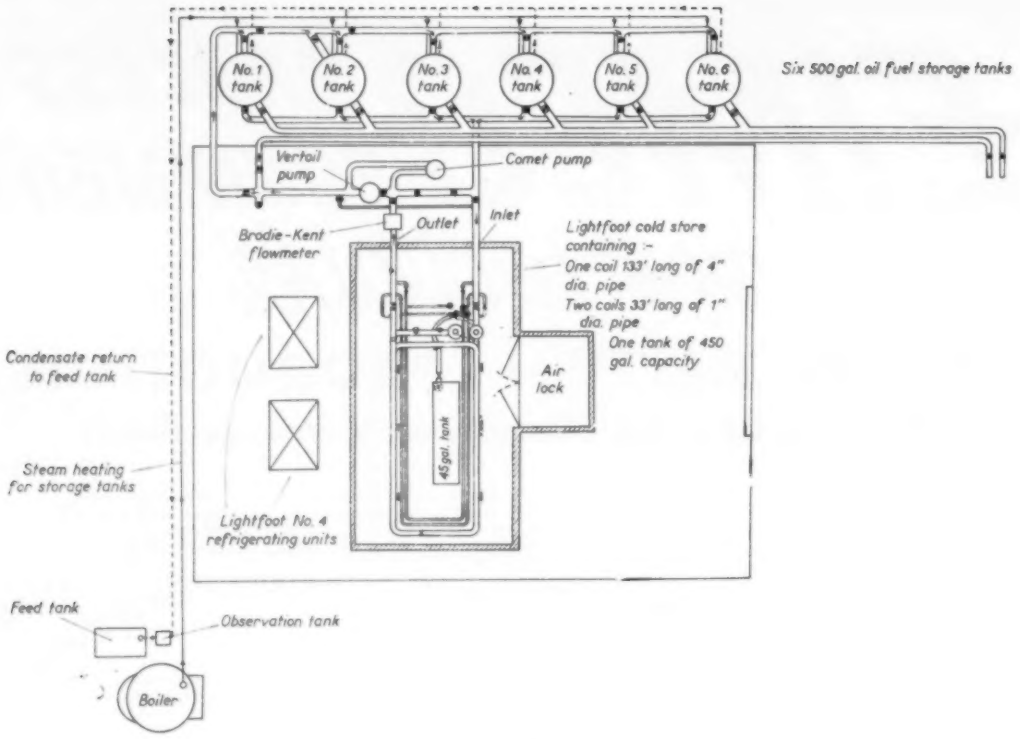

Coolly Studying Fuel Oil Pumpability

TO enable them to conduct line clearing experiments under controlled conditions, the Admiralty Oil Laboratory constructed a pumping rig small enough to be housed in a cold room. An instrumented length of 4 in. i.d. pipe was connected to the suction side of a 4 to 5 in. Drysdale Vertoil (gear wheel type) pump driven by a d.c. motor. In addition for some of the earlier trials a Comet 1¼ in. positive displacement pump (spring-loaded vane type) was used, parallel to the large pump. Six storage tanks were provided outside the room, and one inside the room ; all tanks could be connected to the suction side of the pump either directly or through the instrumented length, or to the discharge side of the pump. Provision was made for measuring temperatures, pressures, and flow rates, all indicating instruments being concentrated at one spot outside the room for easy use during experiments. The layout of the rig is shown in the diagram above. The oils studied were respectively of flow points 50°F, 30°F and 45°F; the Redwood No. 1 viscosity at 122°F of the first of these was 110 to 120 sec., and for the two others 180 sec. It was decided to concentrate on work at 36°F with subsidiary trials at 48°F and 32°F.

What were the conclusions ?

In a paper presented at a Symposium on Flow Properties of Admiralty Fuel Oils D. WYLLIE and J. T. JONES reported results of great practical value. The increase in flow rate on starting up with a pipe full of cold oil was found to be very similar to the increase in rate of shear when the oil is sheared in a coaxial cylinder viscometer at the constant shear stress applied to the pipe. The yield values obtained in a narrow bore yield value tube subjected to a shear stress which is increased by about 30 dynes/sq. cm every 5 min. in general give an indication of whether the line could be started up in about an hour. Furthermore, pipe viscosities after steady flow has been established are comparable with laboratory viscosities as determined in a coaxial cylinder viscometer at the rate of shear presumed to exist in the pipe. If the laboratory viscosities are taken after a time of shearing equal to half the mean residence time of the oil in the pipe, pipe and laboratory viscosities are in good agreement.

The complete proceedings of the Symposium, including the discussion, have now been published in the May and June 1960 issues of the *Journal of the Institute of Petroleum*. Reprints bound together in one volume are available from the Institute.

Calculating Resistance in Pipelines used for Hydraulic Transport

AFTER a careful, critical review of the methods available, J. NOVAK has concluded that an exact solution of the problem of determining pipeline resistance is not possible for all hydromixtures. In a paper in *Strojirentsvi* (1960, Vol. 10 No. 5, p 345), this type of suspension is divided into 3 groups. First there are fine suspensions, in which the particles do not exceed 0.1-0.7 mm ; these are considered in terms of the equivalent homogeneous liquid. Computation of resistance on this basis leads to acceptable results even though most of the important properties of these materials are neglected. Suspensions with particles in the range 0.1-10 mm are considered to form a transitional group. Equations are presented for both of these groups.

The problem is much more complicated for coarser suspensions and the available mathematical expressions differ markedly. In general, the resistance will be affected by the number of impacts between the particles and the pipe walls and between the particles themselves. Hence, specific resistance may be expected to be higher in smaller pipelines and the reviewer is therefore critical of proposed expressions in which pipe size does not appear as a para-

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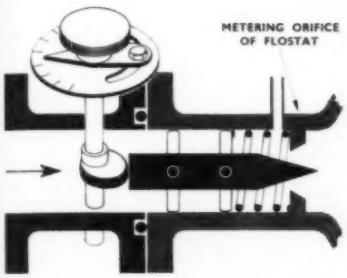

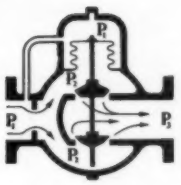

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Flostats and Gapmeters are made in materials for all industrial fluids. Please write or telephone for further information.

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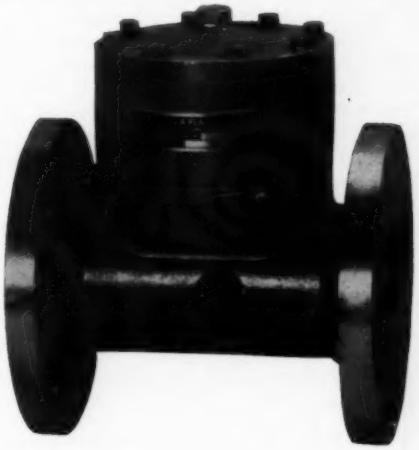

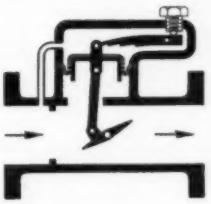

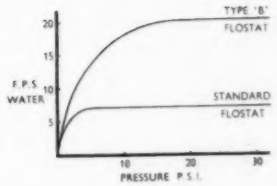

The Type "B" Flostat self-acting flow governor is intended for protective duties. The butterfly valve limits maximum flow but offers least resistance to normal flow.

Flostats Type "B," either Factory Calibrated or adjustable on site, are made for pipe sizes 2½″, 3″, 4″, 6″, and the range is being extended. Prices are from £35. Where visual indication of flow rate is required a Gapmeter can be used in a by-pass line round the metering orifice and the Flo-scan Alarm Switch can be fitted to give a remote signal of low or high flow rate.

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meter. A number of graphs are presented to show the differences in results obtained in applying the various expressions available. INZ. NOVAK concludes that the effects of basic variables can largely be combined and expressed analytically in accordance with the three types of hydromixtures. These groups can be defined with relative ease and thus the placing of any hydromixture into the appropriate group and the choice of a suitable formula is largely a matter of classification.

This is a field of work of growing interest. We understand that the Research and Development Department of the Central Electricity Generating Board have made a preliminary assessment of the feasibility of pumping coal from pit to power station. They are now embarking upon detailed design studies of specific typical applications. These studies are being undertaken in conjunction with a programme of experimental work on pipeline flow, coal drying and other associated problems. It is expected that in two years, sufficient information will be available to indicate whether this method of coal transport is sufficiently attractive to warrant the construction of a prototype installation.

De-polymerising by Electro-Hydraulic Effects

LAST February (p 82) we referred to Soviet work on an electro-hydraulic crushing technique for coal. A powerful spark was passed through a suspension of coal in water and the resulting shocks yielded a fine dispersion of the coal. Similar techniques have been applied for de-polymerising high polymers as a means of preparing active macro-radicals for further reaction. Mechanical abrasion or ultrasonics may also be employed for the same purpose. Using the spark method a series of explosions is produced in a solution of a polymer in a monomer. Thousands of amps are passed for a few micro-seconds repeatedly at intervals which may range from half to one and a half seconds. At each discharge there is a sharp rise of pressure in a swiftly expanding discharge channel yielding a hydraulic shock and producing a cavity. The latter then collapses producing a secondary cavitational shock. This results in chemical breakdown of the polymer. The free macro-radicals thus produced then react with the monomer.

At a meeting of the Plastics Institute (London Section) DR. M. S. AKUTIN stated that this was one of the methods for producing co-polymers which would combine diverse properties in the one material. As examples he quoted linking the heat resistance of phenolic resins and the elasticity of rubber in one product. By means of the spark technique it had proved possible to obtain such grafts as fluorine-containing polymers with polymethyl methacrylate or polyvinyl chloride and polymethyl methacrylate. DR. AKUTIN—who is Director of the Moscow Plastics Institute—also dealt with many other aspects of obtaining block and graft co-polymers, as well as the laws governing their change of properties. One section of his lecture reviewed methods of obtaining graft co-polymers by the use of various fillers (including inorganic ones), reacting with active surfaces developing in the process of mechanical dispersion.

Heat Transfer to Polyphenyls

AS part of the general research development programme for an organic-cooled and moderated reactor power plant the U.S. Atomic Energy Commission has sponsored work to obtain the relevant heat transfer data over a range of surface temperature from about 600°F to 900°F. A recent report* includes relevant information on various polyphenyls flowing turbulently in a tube heated by passing alternating current through the wall. The polyphenyls were diphenyl, Santowax R (commercial mixture of terphenyl isomers) and Santowax OM (a 2:1 mixture of ortho- and meta-terphenyls). The measurements were made in a stainless-steel loop consisting of a centrifugal pump, strainer, turbine flowmeter, test heater section, surge tank, with accessories, connecting piping and valves. The test heater section was a type 304 stainless-steel tube, 0.375-in. o.d. by 0.016-in. wall having a heated length of 24½ in. Fluid temperatures ranged from 480° to 770°F and velocities between 5 and 25 ft/sec. The corresponding range of Reynolds number was 20,000 to 300,000 and the heat fluxes extended from 40,000 to 290,000 Btu/sq ft hr. Heat-transfer coefficients found ranged from 340 to 2740 Btu/sq ft hr °F and were satisfactorily correlated. Other forced convection studies at present under way on Piqua-type extended surface channels are intended to permit more accurate determination of fin efficiencies. It is considered that considerable further work in all phases of forced convection and boiling heat transfer, including the accurate determination of burnout heat fluxes, must be completed before the operation of large organic-cooled power reactors. Burnout heat fluxes have been investigated in a different piece of apparatus by increasing the electrical power input by increments until the tube was damaged and/or the tube wall temperatures rose rapidly to a high value indicating film boiling.

The report—a general evaluation of the technological and economic status of this type of reactor—forms part of a considerable publishing effort by the Commission setting out the progress made in the U.S. Civilian Power Reactor Program. A total of eight volumes is due to appear. Each deals with a different reactor design.

* "TID-8518(7) Book 7 Civilian Power Reactor Program Part III Status Report on Organic-cooled Power Reactors as of 1959." Published: 1960 United States Atomic Energy Commission. $2.25.

Research in Universities

MATERIAL on scientific research at British Universities during 1959-60 has been collected by the British Council and, as in previous years, published under the auspices of D.S.I.R. Entries are arranged in alphabetical order of university; name and subject indexes are provided. This is a reference work,* the value of which could be increased by a clear indication of the basis of the indexing. Consider for example the subject "Control of Precipitated Particle Size" under investigation by DR. F. P. STAINTHORP at Manchester. It cannot be found in the index under any of the key words of the title. Yet users are more likely to want to use this potentially valuable book by the index to check what is happening in a field that interests them, than by the list of universities.

Some two years ago we also mentioned the increasing amount of research, of a calibre leading to higher qualifications, in progress at technical colleges. The question of compiling a parallel list of these projects, or one united with this one, is apparently still under consideration. The Ministry of Education often state that they aim to raise the status of technical teaching. Would not the publication of notes on technical research work in progress contribute greatly to this objective ?

* "Scientific Research in British Universities. 1959-60." H.M.S.O. 1960. £1 5s. 0d.

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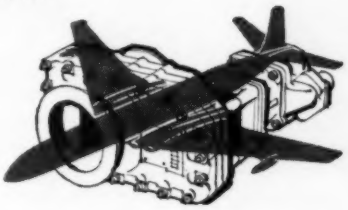

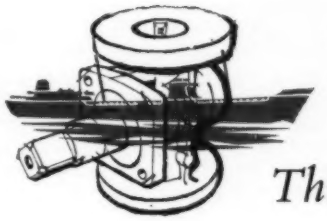

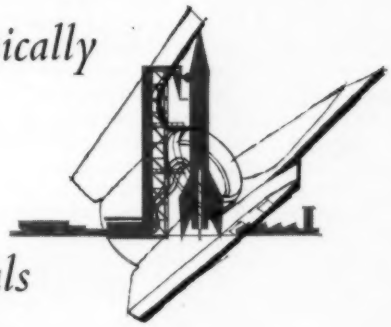

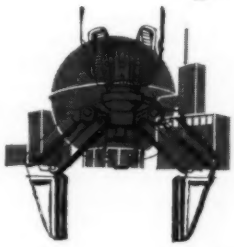

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TRW/703

Can Resonance be made an Asset ?

RESONANCE may be a nuisance on plant where there is a source of vibration and it happens to have the right frequency. Some workers at the Kharkov Experimental-Constructional Bureau however state that they have used the effect to increase the capacity of refrigeration compressors. The resonance occurred due to coincidence between the frequencies of vibrations caused by motion of the compressor piston and those of the natural oscillation of a gas column in the suction line. In *Kholodil'naya Tekhnika*., 1960, No. 3, p.18, Eng. I. EL'KIN and his colleagues discuss the problem in principle and report a detailed examples. The capacity of one of their compressors with synchronous rotation speed of 3000 rpm could be raised by 7.5% on increasing the length of the suction pipe from 100 to 250 mm. According to our enquiries this possibility has been considered in Britain but the idea is not being applied. Has it been tested and rejected, or not yet been investigated ?

Radon Monitor

RADIATION sources are now being increasingly used in industry and with them the necessary detecting equipment. A useful means of calibrating the latter is by employing a sealed radium source. With a half-life of 1612 years, this is effectively constant for most practical purposes. However if there is a fracture in the case of the source, radon gas will be released into the air. The Electronics and Health Physics Divisions of the U.K. Atomic Energy Authority have therefore developed a radon in-air monitor which could in fact be used for any alpha-active gas. The maximum permissible concentration in air for long term exposure to radon and its daughter products is 10^{-13} c/cu cm. Fracture of radium sources of the order of 100 mc can thus give rise to an appreciable hazard. In the instrument (described in Report AERE — M 660 by W. G. SPARKE and J. A. B. GIBSON 1960) the daughter products are filtered out and the hazard determined by measuring the alpha activity of the radon. The 5.5 MeV alpha particle emitted in the decay of radon ($_{86}Rn^{222}$) to radium A ($_{84}Po^{218}$) is detected by a large screen scintillation counter. The instrument measures the pulse rate, due to these alpha particles, from the scintillation counter and hence the radon-in-air concentration. The measured sensitivity for 10^{-13} curies of radon per cu cm of air is 5 counts per second; the background level is less than 0.4 counts per second. The activity level is displayed on a meter in terms of counts per second on successive ranges from 1 to 10^5 counts per second full scale and facilities are available for operating a chart recorder. An audible warning circuit is incorporated.

T.V. Chromatography

LINKING high-speed gas chromatography on a nylon capillary column with display of the resultant graph on a cathode ray tube, a new so-called gas chromatoscope is likely to have a great impact on schemes for process control. Designer of the instrument is R. P. W. SCOTT of Benzole Producers Ltd.—the marketing and research organization of the British benzole industry—and it was first displayed at the Edinburgh Symposium on Chromatography. The column is normally a coiled nylon capillary of 0.4 mm internal diameter but other columns may also be used. Liquid phase is applied as a thin film, roughly 10^{-4} cm thick by blowing through a plug of liquid. With argon as the carrier gas, a constant quantity of sample is injected into the column by an ingenious solenoid operated device at pre-set time cycles. Analyses can be completed in times down to 5 sec. This must be the nearest approach yet achieved to eliminating the basically cyclic character of this analytical method. A Lovelock micro-argon detector supplies a signal to a long-persistence cathode ray tube where it is immediately visible. The spot on the C.R.T. follows the electrical signal input and traces a series of peaks, each corresponding to an eluted component from the column. This eliminates the comparatively long time lag of conventional chromatographic techniques with the possibility of product waste due to the time of analysis, although there will of course remain the effect due to the time constant of the plant. The device is being produced by Bruce Peebles & Co. Ltd. of Edinburgh.

During a recent visit to the Benzole Research Laboratories at Watford we saw both this equipment and an ingenious falling-bed packed chromatographic column. The latter is based on the design principle of moving the column downwards a little faster than the slowest travelling eluted component upwards; feed enters half-way up the column and a gas phase passes through in the normal way. Thus the last eluted component is discharged at the foot and the others at the top. It has already proved possible to separate paraffins (top) from aromatics or even benzene (top) from toluene and xylene. Could this be the basis of a large-scale separation technique ?

Safeguarding Flames by Detecting Ultra-Violet Radiation

A SATISFACTORY flame failure device should meet a number of requirements—among them, reliability and preventing fuel being supplied to a main burner until the pilot flame is established. The subject has been treated in great detail by the Gas Council in a report which we reproduced in full*. At the heart of all such devices is the detector and many types have been proposed. One based on the unexpected method of detecting the ultra-violet radiation from flames may well overcome the difficulties experienced with elements based on photo-electric methods.

Unlike these, the Ultra-Vision detector (Honeywell Controls Ltd.) is actuated only by ultra-violet radiation in the wave band 0.2 to 0.26 microns which is said to be present in all flame. It is completely insensitive to infra-red radiation set up by hot refractory. It discriminates sharply between flame and simulated flame conditions. For pilots it can be placed close to the flame; for main flames it can be set up at a distance and it performs equally well in either case. The detector can be directly substituted for the flame detector in existing rectification type systems.

In the gas industry a major consideration is that any device must be linked with a safe start relay since two thirds of the explosions in gas heated industrial equipment have been connected with lighting up. However these are devices of this kind to link with detectors and, with them, it is emphasised that gas heating is perfectly safe.

* I.G.D.C. Report No. 611/56 of the Gas Council. *British Chemical Engineering*, 1957, **2**, No. 12 and 1958, **3**, No. 1.

DIARY

British Association for the Advancement of Science

August 31-September 7. At Cardiff. Annual Meeting.
August 31. "The Two Aspects of Science." Presidential Address by Sir George Thomson, F.R.S. **8 p.m.**

September 1. "Statics and The Engineer. "Presidential Address of Section G Engineering, by Sir Alfred Pugsley, O.B.E., F.R.S. **10 a.m.**

POPULARITY OF THE DIPLOMA IN TECHNOLOGY

THE new "Dip. Tech." has found a warm welcome amongst technical colleges, industry and young men and women now on the educational ladder to scientific success. Its popularity is reflected in figures issued by the National Council for Technological Awards in their annual report, published recently.

There are now 95 recognised courses at 23 colleges leading to the award. Nearly 4,000 students—including 84 women—have been enrolled. A total of 163 students, including one woman, have now been awarded the Diploma, equal in standing to an honours degree at a university.

The report says the number of students attending the first year of courses continued to increase. The number now enrolled in the first year is 1,558, against 1,171 in March last year. This total includes 40 women, and the Council hope that the first award of the Diploma in Technology to a woman student last year "will encourage more women to take up careers in the field of technology."

Out of the total number of students registered, the great majority, 3,442, are studying for the award by the "sandwich" course method entailing alternate periods in industry and at college. Comparative figure last year was 2,323.

The Council's report mentions the requirement that students following courses leading to the Diploma should be able to participate in a "substantial" research project, and gives instances of the advanced work involved. In some cases, the projects are selected by the students themselves; in others, they are devised having regard to the particular interest of the student and any specialised equipment which may be available

In one instance, work involving a comparison of measured and calculated vibration frequencies of sheet metal was carried out by means of a computer which the college possessed; in another, a student's work on the thermal conductivity of powders involved developing a design theory for an instrument; the results were so successful that they are later to be published by the student jointly with his industrial supervisor. In some cases industrial firms assist students by providing equipment for experimental work to be carried out in the college.

In May 1959, the Council established The College of Technologists, Membership of which constitutes an award higher than the Diploma in Technology, broadly equivalent in standard to the Ph.D. degree of a university. By the end of March this year, nine applications to register as candidates had been received. Five were registered as candidates for Membership and three other applications were still under consideration.

The Council have always regarded a course leading to the Diploma in Technology as a complete entity, the industrial training being just as much a part of the course as the academic study. With their Annual Report they publish a Memorandum setting out their requirements regarding the industrial training of students for the Diploma. The Memorandum defines the responsibilities of firms providing industrial training and of colleges which the students attend, and outlines particular information about industrial training which will in future be required by the Council before they recognise a course.

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A vacancy exists for a chemistry graduate, preferably Ph.D. standard, of age group about 30/35 years. Position involves control of laboratories engaged in plant control and development in the field of fats and related chemicals. Apply, stating experience, qualifications, and salary required, to General Works Manager, Armour Hess Chemicals Ltd., Littleborough, Lancs.

Draughtsmen are required immediately to fill vacancies caused by promotion of existing Drawing Office Staff in an organisation which is expanding rapidly in order to deal with an increasing programme of capital development. Men aged 22 - 30, preferably with experience in chemical plant design, piping and plant layouts, who would welcome the opportunity to work on a variety of projects and are willing to accept responsibility are invited to apply.
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Confusion on Units

THE growing interchange of scientific and technical information on an international scale and the increasing pressure of foreign trade—we have not only the Six and the Seven, but the prospect of greater trade with countries outside this grouping—are factors underlining the need for the universal use of a common system of units. And since it is generally accepted that this should be the metric system, it is pertinent to inquire of the steps the non-metric countries have taken in this direction.

In the United Kingdom, sad to relate, there is little evidence of any real progress in this direction, and even the necessary initial steps appear to have been no more than contemplated. However, the magnitude of the problem of changing from one system of units to another, with its complexity and its host of widely differing obstacles, should not be overestimated. At the same time it should be recognised that within the metric camp itself there exists some controversy as to what the metric system should actually be, for the choice has to be made between the absolute and the gravitational systems. To review this facet of the subject briefly, the absolute system depends upon three fundamental units of length, time and mass, whereas, by contrast, the gravitational system has as its third basic unit not mass but force, mass in this system being a derived unit, while in the absolute system the derived unit is force.

The absolute (CGS) system enjoys world-wide usage in the sphere of pure science, while in technology a system based upon the metre, kilogram, second and ampere, known as the MKSA system, has already gained the official adherence of many countries including India, China, the Soviet Union, and the Eastern grouping of contries, Japan, Switzerland, Norway and Sweden. Moreover, other European, Asian and African countries are contemplating its adoption.

An interesting feature of the MKSA system is that, by using the watt, kilowatt and so on, as the unit of energy rate, it abolishes that survival of the early industrial era, the horsepower. In addition, by using the joule as the unit of energy instead of the calorie or kilocalorie, and the bar rather than atmosphere, or dyne per square centimetre, as the unit of pressure, the MKSA system reveals a number of points of difference from the conventional metric system. In passing, it is interesting to note that in Germany, in order to avoid confusion between the kilogram-mass of the absolute system and the kilogram-force of the gravitational system, a new unit, the kilopond, has been introduced to replace the kilogram-force unit.

It is clear, then, that the transition to the metric system for engineering is not just a simple matter of shifting from the British units to the metre and kilogram, for among the followers of the metric system a great deal of disagreement exists over which metric system should be used, whether this should be the metre, kilogram, second ampere absolute system, the gravitational counterpart of this system or the centimetre gram second absolute system.

Therefore, before a proper choice can be made by the would-be-converters to the metric system, measures to resolve these difficulties need to be set in motion. In short, we must know which metric system to use.

In favour of the MKSA system is the fact that it is an integrated system based upon standard values of length, mass, time and electricity; energy in this system of whatever kind is specified in the same terms, so that in the case of a thermal engine performing work for example, there is a direct comparison between its energy output with its energy input, which thereby gives the thermal efficiency. It is interesting to speculate upon the effect of this feature upon technical thermodynamics. Another point in favour of the MKSA system, apart from its expanding use among the countries named, is that already in Sweden and Switzerland technical tables involving energy such as the thermodynamic properties of steam are given in the MKSA system.

If it is granted that this system is the most convenient choice, what should be the first moves towards its adoption? Take the case of the process industries in which there are many examples of energy flow. Since the watt (or kilowatt) is well understood in both design and operation, this could well be a starting point, one which would permit the inter-changeability of work and thermal effect. A good example of what this would mean is provided by the practice of refrigeration; the refrigerative effect is usually expressed as a number of Btu's absorbed per unit time, and is specified by that awkward unit, the "refrigeration ton", equivalent to 200 Btu per minute. This could be readily changed in favour of the kilowatt of refrigeration which would amount to 3415 Btu per hour. Serious objections to this simple change are difficult to visualise and other equally simple steps to follow could be the substitution of the kilowatt for the horsepower, and a more far-reaching change—the use of the watt or kilowatt in heat transmission.

The recording of data, another very important field which would be closely affected by the change-over, has its own peculiar problems and many existing practices such as those using units of time, other than the second, will prevail for many years to come. Nevertheless, within this sphere there is at least one interesting approach to the question of transition and that is to extend the use of dimensionless numbers as a means of representing a property. Thus it would be possible to convert such values into any system of units by means of a suitable conversion factor; there is indeed a precedent here, for the specific heat is an example of a recognised term of comparison which is readily transformed into any system of heat units, by means of the proper conversion factor. Specific gravity and dynamic viscosity are other dimensionless terms in frequent use which permit similar ready conversions.

Meanwhile, until the preliminary steps have been taken, it seems that it will be necessary for engineers to be "multilingual" in respect of the various unitary systems; they must be able to switch with facility from English to the metric systems, and within the metric systems from the MKSA to its CGS version.

66.074

INDUSTRIAL GAS CLEANING

A survey of industrial equipment available for the separation, agglomeration and collection of dusts and mists

by N. PILPEL, B.Sc., Ph.D.

THERE are five principal methods which are employed on an industrial scale for removing small particles and liquid droplets from gases and vapours. These are filtration, electrostatic precipitation, inertial separation, wet scrubbing and agglomeration. The purpose of this article is to review recent developments in the theory underlying these methods and to describe equipment which is in current use in industry for the treatment of smokes, dusts and mists.

Filtration

Filtration is employed for the removal of particles of all sizes from the coarsest, greater than 500 μ in diameter which are visible to the naked eye, to those of about 0.2 μ in diameter which occur in oil mist or in chemical smokes (Fig. 1).[1]

The filter is a number of small, cylindrical fibres over which the aerosol passes in streamlined flow, and collisions occur between the moving particles and the stationary fibres. For particles which are large in comparison with the fibres, the number of collisions is increased by inertial and gravitational effects. But when they are small (*circa* 0.2 μ in diameter), inertial and gravitational effects become negligible and Brownian motion then predominates, causing small particles to deviate from their streamline path and collide with fibres which they would otherwise miss.[2]

A number of theories[3, 4] have attempted to explain filtration on a quantitative basis on the assumption that every collision between a particle and a fibre is effective and removes it from the gas stream. However, in other theories these ideas have been modified. Langmuir,[5] for example, makes allowance for the diffusion of particles in the neighbourhood of the fibres and also takes account of slipping of the gas over the surfaces of the fibres, while Davies[6] has developed equations which allow for the inertial effects of all the different-sized particles present in the aerosol. Despite these modifications, there are still found to be considerable discrepancies between the predicted results and those observed experimentally, Langmuir's treatment tending to overestimate the efficiency of a filter and Davies' to underestimate it. This is illustrated in Table I.

The reason for the discrepancies between the observed results and those predicted by theory is that there are very many factors involved in a filtration process. Besides the more obvious ones of interception, diffusion, slipping, inertia and Brownian motion, other factors which influence the process are the nature of the particles, the nature of the filter, the geometric arrangement of its fibres and the presence on them of electrostatic charge. Gillespie[7] has

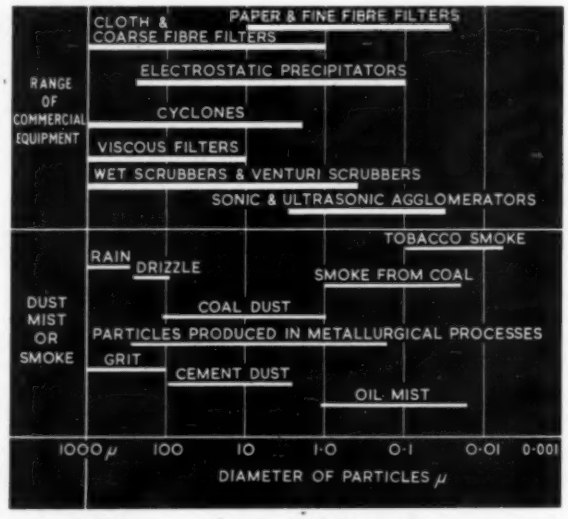


Fig. 1. The range of industrial dust cleaning equipment.

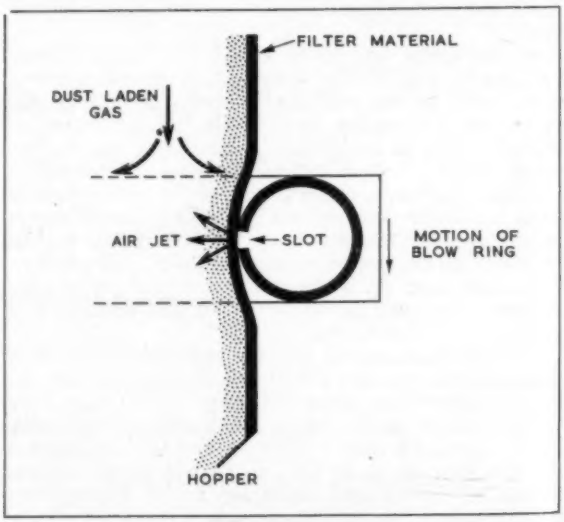


Fig. 2. A blow ring in reverse jet collector.

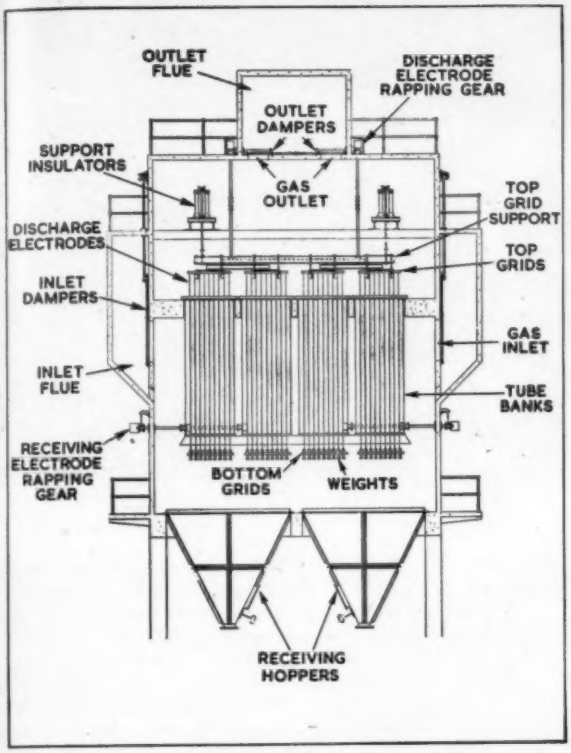


Fig. 3. Cross-section of tubular electrostatic precipitator with vibrator rapping gear. (Courtesy Sturtevant Engineering Co.)

TABLE I—Penetration of Particles Through a Fibrous Filter[3]

Radius of fibre, 1 μ			
Particle radius, μ	Penetration, %		
	Langmuir	Davies	Observed
0.04	4.6	69.0	52
0.05	7.2	63.5	40
0.10	11.0	41.5	25
0.20	5.0	17.0	12
0.30	0.9	6.0	3

TABLE II—Operating Results from Mikrocollector[1]

Materials	Filtering rate/sq. ft. of felt area in cu. ft/min	Particle size, μ
Carbon black	7–16	5
Dyestuffs	10–20	20
Kaolin	12–29	30
Soap powder	19–30	70–80
Cement	14–20	20–30
Magnesium trisilicate	4–9	20–30

TABLE IV—Summary of Performance of Cyclone-type Dust Collectors[24]

Type of Collector	Pressure drop, in. water	Overall collection efficiency, %	Reduction in average deposit rate, %	Reduction in plume blackness, %
Scroll collector	0.5–1	71.2	98.5	19
High-throughput cyclone	2–3	80.8	99.2	38
High-efficiency cyclone	2–3	91.3	99.5	60
Multi-cyclone	1.5–2	92.8	99.7	65

shown, for example, that the existence of even weak electrical charges on the filter considerably affects the filtration process, while La Mer,[8] Ramskill and Anderson[9] and others have drawn attention to the effects of particle size distribution, rate of flow, nature of the filter material and the gradual clogging of the pores which occurs as filtering proceeds.

Filters

The filters which are employed in practice are made either of some type of woven material, e.g., wool, cotton, nylon, metal, glass, or of a specially fabricated mass of fibres, e.g., paper, asbestos, felt, or glass wool. A common form of filter for industrial gases is a tubular bag between 5 and 18 in. in diameter and up to 30 ft long. These bags are connected to the gas inlet and, when several are employed together, constitute a bag-house.[10] The gas permeates the bags, dust, etc., remaining on the inside; this is subsequently removed either by vigorous agitation or by employing a reverse jet of air.

The blow ring technique is used in the Hersey filter, first developed in 1953[11] and now manufactured in the U.K. under licence from the Metals Disintegrating Co. Inc. (N.J.). The bags are made of dense felt. Each is fitted with a blow ring which moves automatically along its length (Fig. 2), and which is fed with high-pressure air from a blower or centrifugal fan. The reverse jet of air displaces the dust from the inside of the bag and it falls into a hopper from which it is withdrawn at intervals. In this way filtration is made a continuous process. The technique is also used in the Mikrocollector, made by Bramigh & Co., London, and some operating data for this equipment are given in Table II.

A recent development in this type of equipment is the Mikro-Pulsaire, now being manufactured by Pulverizing Machinery Ltd., Bristol.[12] This has the advantage of no internal moving parts, the reverse jet of air being applied through nozzles placed vertically above each of the filter cylinders. In a field trial on gypsum dust the collector operated for over 5 months without any maintenance or breakdown, running 24 hr a day, 6 days a week. Another unit, filtering copper powder, had no failures over an operating period of 2000 hr.

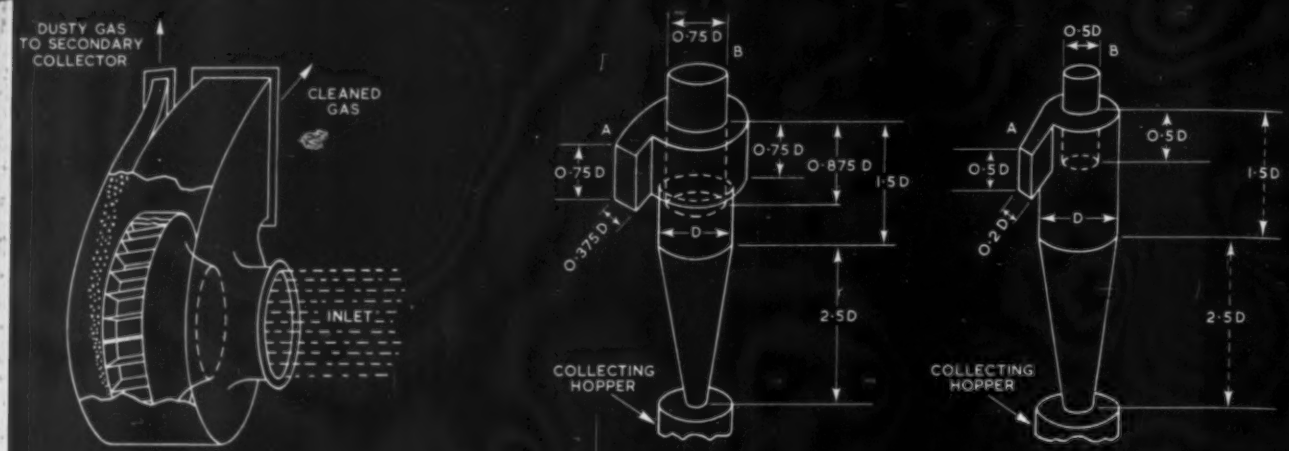
In general, the collection efficiency of bag filters (with or without reverse air jets) is greater than 99%. The main limitation arises from the fact that felt is damaged at temperatures above about 90°C, particularly if acid or alkaline vapours are present. However, the difficulty can be overcome by replacing wool felt by certain synthetic or inorganic fibres which also possess felt-like properties and current research is aimed at improving such filters for commercial and industrial use. For example, Pulverizing Machinery Ltd. have under development a filter medium capable of withstanding temperatures up to 1000°C.

Ceramic Filters

In this connection attention is turning to ceramic filters for high-temperature gas filtration and a promising material is Fiberfrax.[13] This consists of about equal parts of alumina and silica plus small amounts of boric oxide, zirconia, etc. It can be fabricated in the form of blankets of varying thickness, or alternatively as cylindrical filter cells or cartridges. In these forms it has been employed in the atomic energy industry for removing radioactive wastes from hot gases and its potentialities in the steel industry and in the gasification of coal are also being investigated.

Fibre Filters

Work has recently been done by I.C.I. on filters for removing fine acid mist and, in particular, sulphuric acid mist from gases.[14] Both Terylene and silicone-coated glass fibres have been used with success on the laboratory scale



and these materials are now being developed on a pilot-plant scale by Mancuna Engineering Ltd. and Nordac Ltd. in conjunction with I.C.I.[15]

Air Filters

In contrast to the above filters which are employed predominantly in industrial processes, equipment for filtering air is generally in the form of flat panels or boxes.

Coarse air filters made by Sulzer consist of sheets of fine brass or steel mesh and are used in textile mills for removing cotton fly and wool fibres from the air in a preliminary filtration process.

Vokes Ltd., London, make air filters capable of dealing with particles with diameters in the range 0.2-5 μ. These employ thin paper, made from a mixture of asbestos and esparto grass, built up into a box. A typical sized filter is approximately $2\times 2\times 1$ ft thick, the paper being pleated and the sheets separated by corrugated cardboard. At a gas flowrate of about 20 ft/min. and a pressure drop across the filter of $1\frac{1}{2}$ in. of water, over 99.9% of all particles down to 0.5 μ are removed.

In other types of filters, known as viscous filters, a suitable material such as metal or glass wool or hemp, possessing a relatively open structure, is coated with a viscous fluid, e.g., oil or grease with a low vapour pressure and a high flash point. The material is packed into a frame, measuring about $2\times 2\times \frac{1}{2}$ ft thick, frequently with the density at the back higher than at the front, so that large particles are removed first. In this way the life of the filter is increased and it can be renewed by washing and regreasing.

Impregnated Filters

Reference has already been made to the fact that the filtration process is markedly influenced by the presence of an electrostatic charge on the material of the filter. Thus wool impregnated with certain resins has considerably higher retention than the pure wool, due to the resin-coated surface acquiring a high electrostatic charge during preparation.[17] Beckacite 1643 (a rosin-modified phenol formaldehyde resin) is commonly used with wool, being applied in grains of about 1 μ diameter which become negatively charged.

Resin-impregnated wool is used in pleated form or wrapped round metal gauze cylinders in parallel flow units.[17] It is also employed in dust respirators of various kinds.[18] The main drawback to filter materials of this kind is that although they have a very high initial efficiency this decreases with time due to the gradual loss of electrostatic charge which occurs as particles (and particularly liquid droplets) are deposited. The resistance of the filters can, however, be restored by periodic vacuum cleaning, and there are possibilities that shock waves, too, might be effective, since it has been shown in laboratory experiments that low-pressure (5 to 10 in. mercury) shock waves can remove up to 90% of collected material from fibre filters of various types without any injurious effects to the filter.[19]

Electrostatic Precipitation

Electrostatic precipitation depends on the fact that under the dual influence of a corona discharge and a lateral electric field, particles in a moving gas become ionised and then move to the electrode whose charge is opposite to that which has been induced on them.

If E_o is the strength of the ionising field and E that of the lateral field, it may be shown that the velocity, U, with which particles of radius r move to the collecting electrode, is given, as a first approximation, by

$$U = \frac{KEE_o r}{6\pi\eta}$$

where η is the viscosity of the gas and K is a number varying between about 1.5 for particles with resistivities in the neighbourhood of $10^{10}\ \Omega$ cm and 3 for those with resistivities of about $10^4\ \Omega$ cm.

But while the principle of electrostatic precipitation has been known for many years (for the early history see [20]), there are in practice many factors which influence the process and which determine the efficiency with which particles are removed from the gas stream.[21, 22] For example, particles with resistivities greater than $2\times 10^{10}\ \Omega$ cm tend to produce back discharge which interferes with the process, while those with resistivities below $10^4\ \Omega$ cm, and particularly if they are large, tend to be re-entrained in the gas stream after reaching the collecting electrode.

A controlling factor is the design of the equipment used. For a single-stage precipitator consisting of a wire at negative potential surrounded by an earthed tube, the efficiency, γ, may be expressed by

$$\gamma = 1 - \exp(-4LU/DV)$$

in which L is the length of the collecting electrode in cm, D its internal diameter in cm, U the mean migration velocity of particles towards the collecting electrode in cm/sec., and V the velocity of the gas in cm/sec. Other expressions are given for the efficiency of a two-stage precipitator in which the ionising and lateral fields are separate.[1]

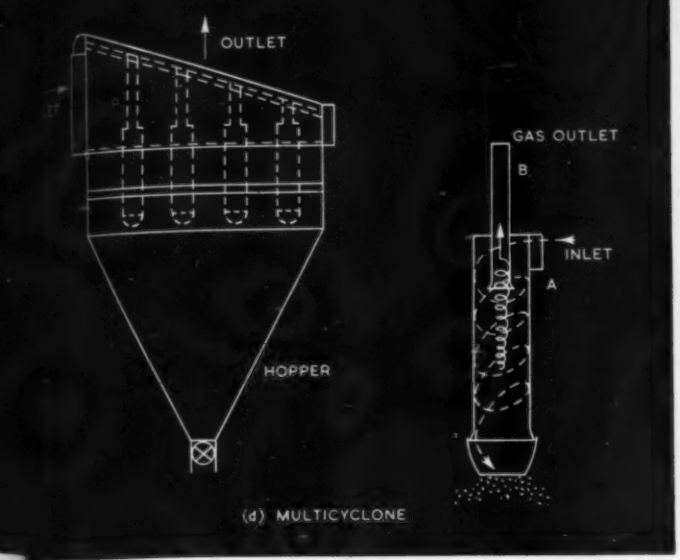


Fig. 4. Various types of cyclone.

Electrostatic Precipitators

A schematic diagram of a typical tubular precipitator, manufactured by the Sturtevant Engineering Co., London, is shown in Fig.3.[23] It consists of banks of vertical receiving electrodes, down the centres of which are suspended the discharge electrodes. The former are circular or hexagonal in cross-section and are usually made of steel, though in certain cases lead or even plastic or ceramic materials are used. The discharge electrodes consist of steel wire which may be coated with corrosion-resisting material for particular applications. The spark gap between the electrodes is about 5 in. and the potential difference between them can be varied from about 15 to 60 kV, with the receiving electrodes connected to earth.

Due to the fact that particles tend to stick to the electrodes and interfere with further deposition, these are connected to a steel framework which can be vibrated intermittently by means of electrically operated vibrators, and the intensity and vibration period are altered to suit the individual requirements of different types of deposit. As this is shaken free from the receiving electrodes, it falls into hoppers below.

Practically every electrostatic precipitator is specially designed for the particular conditions under which it is to operate. Factors affecting design include the nature of the gas, the nature of the material to be removed from it, the temperature of operation, the rate of gas flow and the cleaning efficiency which is required. Conducting gases such as CO_2, SO_2, CO and water vapour are normally present in industrial gases in sufficient quantities to permit smooth and efficient operation of the corona discharge. But in certain cases it may be necessary to introduce water vapour before subjecting the gas to discharge, not only to increase its conductivity but also to reduce its temperature, since this, too, has an influence on the dielectric strength of a gas.[24, 25]

Considering the rate of gas flow in relation to cleaning efficiency, the results obtained depend very considerably on the nature of the material which is being removed. Thus for sulphuric acid mist the rate of gas flow needed to give a cleaning efficiency of 98% will be very different from that required to remove dust with equal efficiency from, say, the effluent from a cement works.

Most electrostatic precipitators operate at gas flow-rates of between about 2 and 20 ft/sec. past the electrodes, it being found that at higher speeds particle re-entrainment becomes serious.[10] To reduce this to a minimum it is important that the vibration or rapping is adjusted to produce relatively large aggregates which can fall rapidly into the collecting hoppers. In two-stage collectors rapping is generally continuous (every few seconds), but in certain types of single-stage collector the electrodes may only be vibrated a few times an hour. A recently patented device is a rotating electrode which is cleaned by brushing, and other collectors of special design, e.g., the Chute electrode, also permit the employment of higher gas velocities than would otherwise be possible.[26]

The total volume of gas that can be handled depends, amongst other factors, on the size of the installation and figures of several 100,000 cfm are common. But the manner in which the gas is passed through a precipitator is important, and in many cases the best results are achieved by dividing the installation into sections which, as regards gas flow, are completely isolated from each other.[23]

A great deal of latitude is permissible in operating pressures and temperatures. Pressures as high as 10 atm. have been employed,[27] while operating temperatures from −70°C to over 1000°C have been reported. But at very low temperatures the gas must be perfectly dry, while at high temperatures special precautions are needed to ensure that warping does not lead to damage to the electrode systems.[28]

Since many types of dust exhibit a maximum in their resistivity at a temperature between about 100 and 150°C, associated with the removal of adsorbed films of moisture and other contaminants, this temperature range involves

Fig. 5. Grade efficiency curves for various types of cyclone.

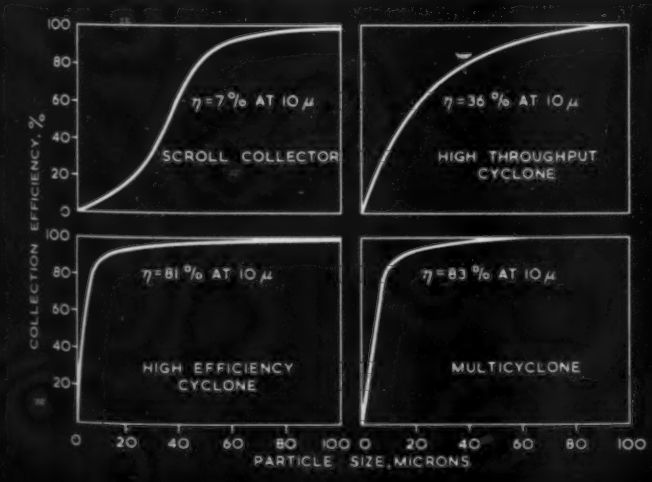
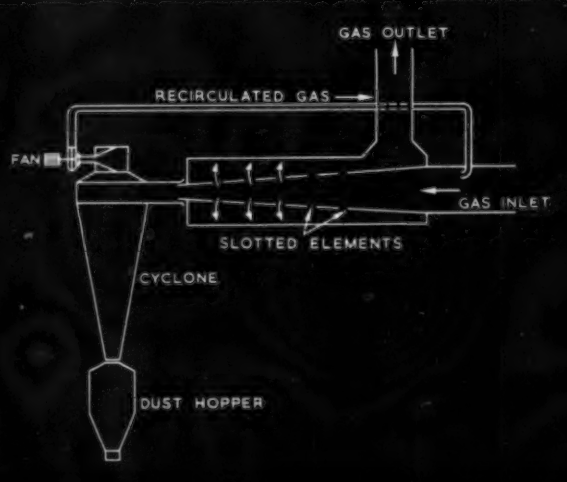


Fig. 6. Diagram of Musgrave Linderoth collector.



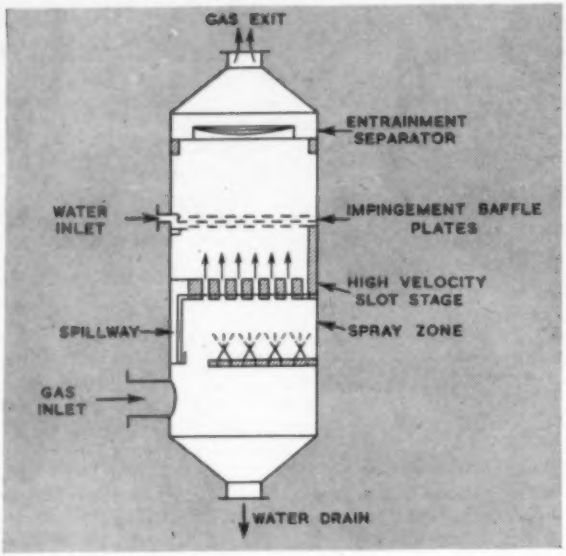


Fig. 7. Peabody high-velocity gas scrubber.

TABLE III—Prediction of Overall Efficiency and Grading of Emitted Dust[24]

Size of grade (a)	Amount in grade at inlet, % (b)	Efficiency at mean size of grade, % (c)	Overall collection, % (d)	Grading of emitted dust as percentage of inlet (e)	Actual amount, % (f)
600–855	1	100.0	1.0		
420–600	3	99.8	3.0	Trace	Trace
295–420	5	99.6	5.0	—	—
210–295	8	99.3	7.9	0.1	0.3
150–210	11	99.0	10.9	0.1	0.3
104–150	12	98.7	11.8	0.2	0.7
76–104	11	97.3	10.7	0.3	1.0
60– 76	8	93.5	7.5	0.5	1.7
40– 60	10	81.5	8.1	1.9	6.6
30– 40	6	45.5	2.7	3.3	11.5
20– 30	6	23.5	1.4	4.6	16.0
10– 20	7	12.0	0.8	6.2	21.6
5– 10	6	5.0	0.3	5.7	19.8
5	6	1.5	0.1	5.9	20.5
			71.2	28.8	100.0

Column (c): From Fig. 4 (a).
Column (d): Column (c) × Column (b) ÷ 100.
Column (e): Column (b) − Column (d).
Column (f): Column (e) × 100/Σ Column (e).

TABLE V—Data for Pease-Anthony Venturi Scrubbers[5]

System	Particle diameter, μ	Inlet concn., gr./cu. ft[3]	Water feed, U.S. gal. 1000 cu. ft	Pressure drop, in. Water	Collection efficiency, %
Sulphuric acid mist	—	2.92	3.0–7.2	9–30	99–100
Blast furnace	0.5–2.0	—	—	—	97
Silica fume	0.01–0.35	—	3.9	9.8	52.4
	0.01–0.35	—	4.7	11.0	86.7

difficulties. If the resistivity rises above the critical level of about $2 \times 10^{10}\ \Omega$ cm, back discharge occurs. The difficulty can be overcome in certain cases by preconditioning the dust-laden gas with additional water or with a fine spray of sulphuric acid. But in other cases the use of two-stage collectors may be preferable.[29]

Electrostatic precipitation is employed in activities as diverse as cleaning flue gases from power stations, recovering metals and metallic oxides from metallurgical plant, removing acid mist from sulphuric acid works, eliminating oil mist from machine shops, and removing bacteria and atmospheric dust of all kinds from the air of offices, hospitals, laboratories, etc.

Inertial Separation

Cyclones

Probably the most widely used device for separating particulate matter from gases is the cyclone separator. This operates on the principle that dust particles through their inertia tend to maintain their direction of flow when the gas in which they are being carried is deflected into a spiral path.

A schematic diagram of cyclone separators is given in Fig. 4. The dust-laden gas enters the cyclone at A and spirals down to the bottom of the cone. During the descent particles of dust are flung outwards by centrifugal force on to the walls of the cone and they slide down into the hopper at the bottom. The clean gas then flows upwards through the turbulent central region of the cone and escapes at B.

Various authors have investigated the movement of particles of dust towards the walls of the cyclone. For example, Davies[30] expresses the time, δt, taken by a particle of radius r and density ρ to travel from radius R_1 outwards to radius R_2 by means of the expression

$$\delta t = \frac{(R^4_2 - R^4_1)\ 9\eta}{8r^2\ (\rho - \sigma)\ V^2 R^2_2}$$

in which η is the viscosity of the gas, σ its density and V is the tangential gas velocity at radius R_2. From this equation it is then possible to calculate how far the particle will travel the length of a spiral path before it collides with the walls of the cyclone and this gives some measure of the equipment's cleaning efficiency.

However, the treatment has been criticised in various quarters and Lapple and Shepherd,[31] for example, obtain a value of δt only one-quarter of that derived by Davies.

Ter Linden,[32] on the other hand, has attempted in both theoretical and experimental investigations to relate cyclone performance to such factors as its height and diameter, the rate at which gas is passing through it, the position of the exhaust pipe, etc. But at the present time there is no generally accepted equation of a theoretical nature. Probably the most satisfactory expression for cyclone performance is still the empirical one given by Rosin, Rammler and Intelmann in 1932[33] which gives the diameter, d, of particles which a cyclone will collect with 50% efficiency. This may be written

TABLE VI—Approximate Costs of Various Cleaning Systems[11]

Equipment	Efficiency on standard dust, %	Capital cost £ Total	Capital cost £ per cu. ft/min. capacity	Water usage, gal./1000 cu. ft	Total running cost including depreciation £/annum	Total running cost including depreciation pence per 1000 cu. ft
Frame-type fabric filter	> 99	18,000	0.29	—	7,000	0.057
Reverse-jet fabric filter	> 99	17,000	0.28	—	8,500	0.070
Electrostatic precipitator	94	31,000	0.51	—	4,000	0.033
Irrigated electrostatic precipitator	99	53,000	0.88	2.5	7,500	0.060
Medium-efficiency cyclone	65	3,000	0.05	—	2,000	0.017
High-efficiency cyclone	84	6,000	0.10	—	3,000	0.025
Spray tower	96	18,000	0.30	18	8,000	0.065
Wet impingement scrubber	98	10,000	0.17	3	5,000	0.040
Venturi scrubber	> 99	15,000	0.25	7	13,500	0.11

$$d = \sqrt{\frac{9\eta B}{2\pi NV(\rho - \sigma)}}$$

where η, ρ, σ have the meanings already used above, B is the diameter of the cyclone inlet, V the average inlet velocity and N the effective number of spirals made by the gas stream in the cyclone. This has to be determined experimentally and is usually in the neighbourhood of 3 to 5.

Cyclones in Practice

In practice, there are many different designs of cyclone, but the four shown schematically in Fig. 4 are the most common.

The Scroll type, essentially a dust-collecting fan having a diameter of about 7 ft, is of relatively low efficiency. Medium efficiency is achieved by the high-throughput cyclone which has a fairly large diameter and is used as a single unit. The high efficiency cyclone is similar in design, but has only medium throughput and is generally used in groups of 2, 4, 8 or more. Finally, in the multi-cyclone very high efficiency is achieved by employing a large number of separate small cyclone units built up into a nest.

Stairmand and Kelsey[34] have compared the performance of these four types using grade efficiency curves to calculate how each would reduce the smoke and dust emitted by a small boiler plant operating at a steam load of 2300 lb/hr, a flue gas rate of 14,000 cfm at 340°F and with 0.7 grain of dust per cu. ft entering the stack at 340°F.

The grade efficiency curves, which are plotted in Fig. 5, show how for each type of collector the efficiency of collection varies with the size of the particles of dust which are present in the gas. Table III, referring to the scroll collector, shows how these curves are then used to calculate the overall collection efficiency and the grading of the dust that is still present in the gas emerging from the collector. Finally in Table IV a summary is given of the performance of the four different types of collector.

It is seen that the overall collection efficiency of the scroll type is only 71.2%, whereas that of the multi-cyclone is 92.8%. Employing Bosanquet's method of calculation[35] for the plant considered, it may be shown that if no collector is fitted approximately 270 tons of dust/sq. mile will be deposited per month at a distance of 300 yd from the plant. With a scroll collector fitted this figure is reduced to 5 tons, and with a multi-cyclone to 1 ton. On the other hand, the rather surprising conclusion is reached that, although all four types of collector substantially reduce the amount of dust that is deposited, even the multi-cyclone is comparatively inefficient in reducing the darkness of the smoke emitted by the boiler, the reduction being 19% for the scroll and 65% for the multi-cyclone.

Cyclones as Secondary Collectors

In many cases it is found advantageous to use cyclones in conjunction with other equipment so that the cyclone is, in fact, operating as a secondary collector. As an example, one can mention the Musgrave or Linderoth collector[36] (Fig. 6).

The dust-laden gas enters a truncated cone of sheet metal which is punched along its length by slots. These set up aerodynamic forces in the gas stream which act on the dust particles in a direction away from the walls of the cone. Dust-free gas escapes through the slots, while the dust, now contained in only about 5% of its original volume, passes to the small end of the cone and thence to a cyclone separator. Since the volume of gas has been substantially reduced, a low-throughput, high-efficiency cyclone can be used and this leads to better results than would have been achieved with one or more high throughput cyclones.

Aerodynamic cones are made in a range of sizes capable of handling from about 500 to about 10,000 cu. ft of gas a min. Where the volume is greater than this, a number of cones can be operated in parallel, all feeding the one cyclone. Another instance in which cyclones are employed as secondary collectors is when sonic or ultrasonic methods have been used in a first stage to agglomerate dust or smoke. This technique has only been applied quite recently on an industrial scale and it will be dealt with separately in a later section.

Other Inertial Scrubbers

The Calder Fox scrubber is another type of inertial separator in which the gas is passed through a series of perforated plates with the openings staggered. The rapid changes in direction cause particles or droplets in the gas to be deposited on the plates. This type of collector usually removes particles larger than about 2 μ in diameter, but it has been used for removing sulphuric acid mists from industrial gases and efficiencies as high as 97% have been reported.[27, 37]

The Allen-Dep curtain arrestor,[38] manufactured by W. G. Allen & Sons (Tipton) Ltd., works similarly, but consists of a number of grids placed one behind the other in staggered formation to form either a single curtain or banks of curtains through which the dust-laden gas is passed. Under suitable conditions efficiencies as high as 99% have been obtained and the equipment is currently employed in cement works, boiler houses and rock-crushing plant.

Washing and Wet Scrubbing

Washing and wet scrubbing are also widely used for removing particulate or liquid material from gases and involve bringing the gas into intimate contact with a suitable liquid which can then be drained away. Several mechanisms appear to operate during the washing of gases, and under particular circumstances some or all of the following may occur[10]:

(a) Direct collision and absorption of particles by droplets of the liquid.
(b) Diffusion of very small particles (less than 0.5 μ), as well as gases into the droplets.
(c) Condensation of supercooled water or other vapours on to particles which are thereby agglomerated.
(d) Entrainment of particles by liquid droplets which have acquired electrostatic charge.

Considering the collection efficiency of liquid drops falling through a cloud of smaller drops, Langmuir[39] developed a theory which is in good agreement with the experimental data[40] provided there is an appreciable difference in size between the falling drops (e.g., 3 mm diameter) and those present in the aerosol (e.g., 5 to 200μ diameter).

When the disparity in size is small the theory fails, partly because the droplets in the aerosol can now no longer be considered as point masses. Some improvement is effected by a modification due to East and Marshall,[41] who replace Langmuir's $E \pi R^2$ for the capture cross-section of a drop by $E \pi (r + R^2)$, where r and R are the respective radii of the smaller and larger drops (see also [47]).

An alternative treatment is due to Johnstone and Roberts,[42] who consider only collisions and diffusion as operating during the washing process. Restricting their treatment to the case of water drops less than 400 μ in diameter falling at different speeds through a dust-laden gas in which the particles range in size from 0.01 to 5 μ, they show that diffusion plays the major role when the particles are less than 0.5μ in diameter. The efficiency of collection due to this mechanism decreases with the diameter of the falling drops (big drops have a proportionately smaller surface area than small ones) and also decreases with their speed of fall. For particles greater than 0.5 μ, on the other hand, collisions play the major role. The efficiency of collection due to this mechanism increases with the size of the particles and also

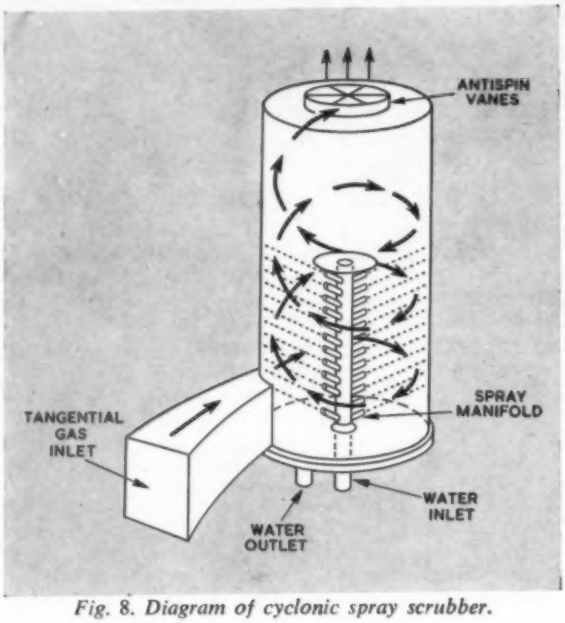


Fig. 8. Diagram of cyclonic spray scrubber.

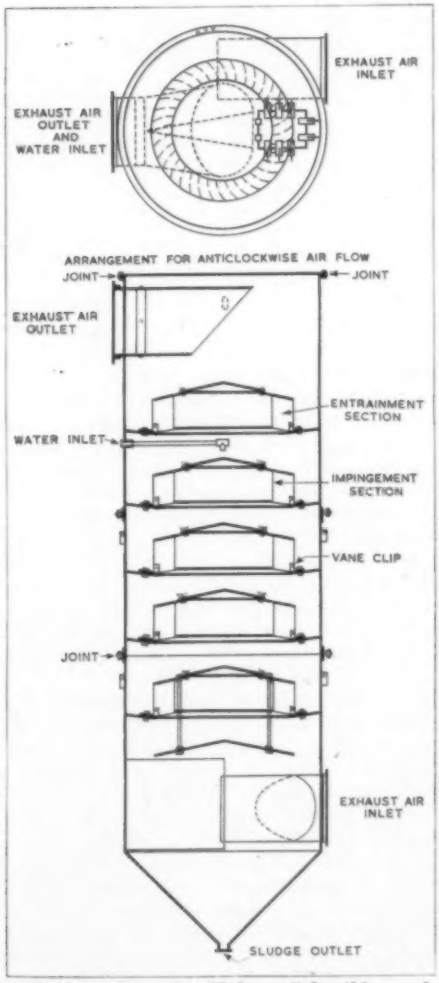


Fig. 9. A section of a Holmes Schneible washer.

with the size of the drops and the maximum efficiency is obtained with drops having a diameter of about 100 μ.

Commercial Equipment

The simplest type of commercial gas scrubbing equipment is the spray tower. Dust-laden gas enters at the base of the tower where it is brought into contact with a spray of water droplets. The gas then passes up the tower past a series of baffle plates on which the water and the dust collect, while the purified gas escapes through the top of the tower

Calculations by Stairmand[4] show that the efficiency of collection in this simple type of equipment is relatively low, reaching a maximum when the droplets are about 800 μ in diameter. However, the efficiency can be improved by modifications in design. For example, the Peabody high-velocity gas scrubber (Fig. 7) is a recent development, incorporating a spray zone, a high-velocity agglomerating stage, an impingement cleaning stage and an entrainment stage in a single shell, and this equipment has given good results in the handling of radioactive wastes, blast furnace gases, salt cake fumes, etc.[44]

In the cyclone scrubber and the rotary washer a similar increase in efficiency is achieved by imparting a circular motion to the incoming gas. This raises the relative velocity between dust particles and the water droplets, thereby increasing the chances of direct collisions. At the same time it assists in ridding the cleaned gas of the washing liquid. A schematic diagram of a cyclone scrubber is shown in Fig. 8.

The Holmes Schneible washer works on this principle and various designs are available.[45] Referring to the equipment shown schematically in Fig. 9, the cone-shaped bottom operates as a wet cyclone, collecting the heavier particles of dust as soon as they enter the tower. Water is introduced above the centre of the top impingement plate and, due to the rotary motion of the ascending gas, is cascaded evenly over the discs, vanes, shelves and side walls of the collector to form a dense curtain of water droplets through which the gas must pass. This removes the dust and it is carried down to the bottom of the cone and run off.

The washer is frequently installed in multi-units, each unit capable of handling up to 40,000 cu. ft of gas a min. It is currently employed in plant manufacturing fertilisers, quicklime, plastics, paints and many other products.

The development of the Venturi throat in the past 10 or 15 years and its adaptation to cyclone scrubbers has still further improved the performance of this type of equipment. Venturi scrubbers were first used on an industrial scale in 1947 to remove salt cake fume from kraft furnace gases[46, 47] and have subsequently been applied to a wide range of gas-cleaning problems (Fig. 9). The scrubbing liquid is injected into or just before the throat of the venturi to form a curtain of droplets through which the dust-laden gas passes at a high velocity, e.g., 200 to 400 ft/sec. Under these conditions collection is effected almost completely by the collision mechanism and diffusion and condensation, etc., play a minor role. Since one mechanism preponderates, it has been found possible to derive an expression for the collection efficiency on a strictly scientific basis, and the equation

$$E = 1 - \exp(-kL\psi^{\frac{1}{2}})$$

very reasonably fits the results obtained by various workers.[48] In this equation E is the efficiency, k is a constant, L the liquid to gas ratio (U.S. gal./1000 cu. ft of gas) and ψ is the collision parameter, calculated for the conditions of the throat. Jones[49] has described installations which are currently operating on open hearth steel furnaces; Ekman and Johnstone[50] give operating data for Pease-Anthony venturi scrubbers (Table V) and Stairmand[51] compares the collection efficiency of venturi scrubbers with those of other types of scrubber by means of grade efficiency curves (Fig. 10).

Against their high collection efficiency must, however, be set the fact that venturi scrubbers are, on the whole, more expensive both to install and to operate than other types of scrubbing equipment. There is a rather high pressure drop across the equipment and considerable amounts of water are used. In fact, with the sole exception of the disintegrator, venturi scrubbers are more expensive to run than any other type of gas-cleaning equipment. This point is illustrated in tabular form in a later section of this article.

Agglomeration

As a result of random Brownian motion, turbulence, thermal gradients and other external influences, small particles of suspended dust normally collide to form larger particles. This process is termed agglomeration, and it has been studied in detail by a number of workers.[2]

Whytelaw-Gray and his co-workers at Leeds[52] were the first to develop reliable methods for counting particles in an aerosol. By measuring the number of particles present at different times, they derived the following expression for the behaviour of smokes under the dual influence of gravity and Brownian motion:

$$\frac{1}{n} - \frac{1}{n_o} = Kt$$

In this n is the number of particles/cm³ at time t, n_o is the number present when the smoke is first formed and K is a constant, termed the agglomeration (or coagulation) constant. It follows that:

$$-\frac{dn}{dt} = Kn^2$$

showing that the rate at which particles agglomerate is proportional to the square of the number present.

Other factors, however, influence the process. For example, the agglomeration constant is affected by the size of the particles, small particles agglomerating faster than large ones. The state of dispersion of the aerosol is also relevant and an aerosol in which the particles are all of approximately equal size coagulates more slowly than one which is polydisperse. The rate of agglomeration is dependent too on the temperature, the viscosity and the mean free path of the gas, and a general equation for agglomeration in aerosols may be written[2]:

$$-\frac{dn}{dt} = \frac{RTS}{6\eta N}\frac{(r_1 + r_2)^2}{r_1 r_2}\left(1 + \frac{Al}{r}\right)n^2$$

In this r_1 and r_2 are the radii of the smallest and largest particles, R is the gas constant, T the absolute temperature, and s the ratio of the sphere of influence to the radius of a particle. A is a constant for the particular aerosol, η is the viscosity of the gas, N, Avogadro's number and r is the mean value of r_1 and r_2. An improvement can be made in the agreement between the results obtained experimentally and those predicted by the above equation by allowing for additional factors such as particle shape and the presence of foreign vapours.

Rotary Screw Agglomerator

A device which makes use of the effect of turbulence for increasing the agglomeration of particles in a moving gas is the rotary screw agglomerator. It consists of a standard conveyor screw which is rotated in a cylindrical steel casing through which the dust-laden gas passes (Fig. 11). Turbulence is produced as the gas spirals through the screw and its effects are reinforced by the collisions which occur between the dust particles and the screw and walls of the casing. Additional turbulence can be introduced by applying counterflow, or by heating the walls of the casing, thus setting up thermal gradients in the gas.

Silverman and Billings[19] have studied the characteristics of rotary screw agglomerators in detail and shown, for example, that for a screw 24 in. in diameter and 140 in. long (representing a gas path of 30 ft), substantial agglomeration of iron oxide fume occurred. The particles in the incoming gas had an average diameter of 0.048 μ, those in the outgoing gas an average diameter of 0.087 μ, representing an increase in diameter of about 81%. In addition, the burden of dust in the gas was reduced as material collected in the hoppers at the base of the casing.

Although so far these experiments have been done only on a small scale, the rotary screw agglomerator appears to have industrial potentialities and further work is planned.

Sonic and Ultrasonic Agglomeration

In recent years promising results have been achieved by employing sonic and ultrasonic vibrations to agglomerate very small particles of dust or smoke, thereby facilitating their collection by one or other of the methods already described.

Theory

The principle of this technique was discovered in the 1930s[53,54] and it is now known that at least three mechanisms operate to produce agglomeration. These are covibration of particles, the operation of hydrodynamic forces and the development of radiation pressures.

The first depends on the fact that when particles are suspended in a vibrating gas they will, in general, vibrate with amplitudes and frequencies which are a function of their size. As a result, particles of different size collide and this produces agglomerates.

The hydrodynamic forces develop as a result of the con-

Fig. 10. Grade efficiency curves for various types of scrubber.

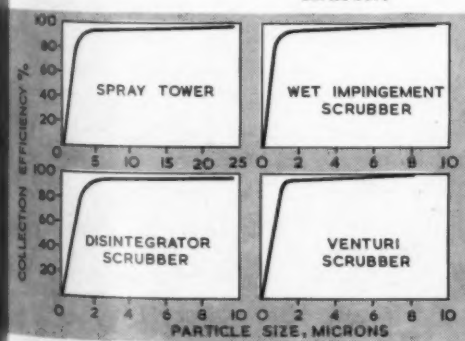
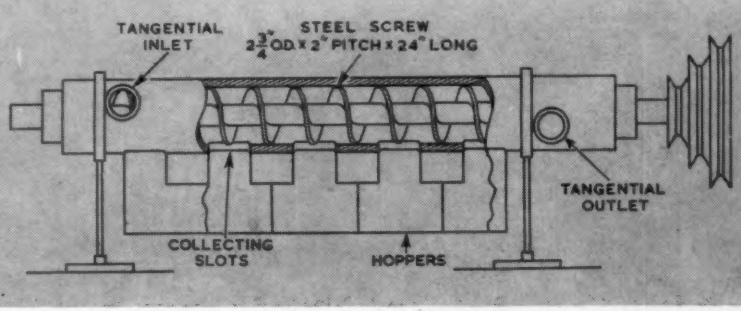


Fig. 11. Under development — rotary screw agglomerator.



stricted flow of gas between neighbouring particles which are moving with high velocities relative to the ambient gas. When the line of centres of two adjacent particles is perpendicular to their direction of vibration, the hydrodynamic forces are attractive and this causes the particles to move together and collide.

Finally, radiation pressures develop whenever small particles are suspended in a standing sonic or ultrasonic wave. The particles are urged towards theh antinodal regions which thereby become congested, and the sheet-like agglomerates are produced.

A more detailed account of the three mechanisms has been given elsewhere.[55, 56, 57]

Industrial Generators

Of the various generators which can be employed for the production of sonic and ultrasonic vibrations,[58] that most suitable for industrial purposes is the siren type.

It consists of an internal rotor facing a concentric stator which has matched ports round the periphery. Compressed air is pumped through the ports of the rotor and escapes through those of the stator in intermittent puffs. This produces a sound wave of high intensity (10 to 50 kW), whose frequency is controlled by the speed of the rotor and can be varied between about 1 kc/sec and 1 mc/sec.

Generators of this type have been successfully used in the United States for agglomerating sulphuric acid mist, soda ash particles and carbon black, prior to their collection with cyclones. The method is suitable for particles in the size range 0.05 to 5 μ, when their concentration in the gas is relatively high, e.g., 1 to 3 grain/cu. ft. In other cases improved agglomeration is achieved by the simultaneous injection of a spray of water into the gas.[55]

One particular merit of ultrasonic agglomeration is that it can be employed on gases which are at a relatively high temperature (>500°C) and which contain non-conducting particles. It can also be used in cases where the gas is inflammable, in contrast to electrostatic precipitators.

However, it should be emphasised that the method is still primarily in the development stage. Indeed, a number of plants in the U.S.A. had to be dismantled after a relatively short period of operation, since it was found that exposure to the intense vibrations was having a harmful effect on personnel in the vicinity.[59] Although in principle agglomerator/cyclone systems are about 20% cheaper to install and operate than electrostatic precipitators of similar capacity, the need for heavy sound insulation raises the cost considerably. This, to some extent, explains why sonic and ultrasonic agglomerators have not yet been employed on an industrial scale in the United Kingdom.

Choice of Plant

It is appropriate to conclude this survey with some general remarks on the economics of gas cleaning methods, since clearly the cost of installation and operation plays an important role in determining what type of equipment is to be installed.

Stairmand[51] has published extensive data on this subject and it is summarised for convenience in Table VI. The data are based on the assumption that 60,000 cu. ft of gas a min. are being treated at a temperature of 20°C. The gas is assumed to contain 5 grain/cu. ft of a standard dust, consisting of 10% of particles greater than 75 μ in diameter, 80% greater than 10 μ and 12% less than 2.5 μ in diameter.

On this basis the following conclusions are reached: As regards efficiency, irrigated electrostatic precipitators, fabric filters and Venturi scrubbers head the list, with cyclone separators of various types some distance behind. Capital costs range from about £3000 for cyclones to over £50,000 for irrigated electrostatic precipitators. But bearing in mind the differences in gas capacity, the need for capital replacement and the amounts of power consumed during operation, the actual cost of cleaning varies from about 0.02d./1000 cu. ft of gas for cyclones to 0.22d./1000 cu. ft for disintegrators. Electrostatic precipitators cost 0.03d./1000 cu. ft of gas, and when the gas is also irrigated with liquid the cost rises to 0.06d./1000 cu. ft.

It is obvious, however, that installation and running costs are only two of the factors involved in choosing gas-cleaning appliances, and this accounts for the diversity of equipment which is, in fact, employed in industry at the present time. In some metallurgical processes the gas is at a high temperature and methods like filtration or scrubbing must be ruled out in favour of, say, electrostatic precipitation.

In other cases, the lack of suitable supplies of water will preclude the employment of wet scrubbing. Where space is restricted it is not possible to accommodate relatively bulky electrostatic precipitators or bag houses.

Finally, as in the cleaning of blast furnace gases, it may be convenient to employ two- or even three-stage collection; e.g., electrostatic precipitators in conjunction with cyclones or ultrasonic agglomerators in conjunction with a bag house.

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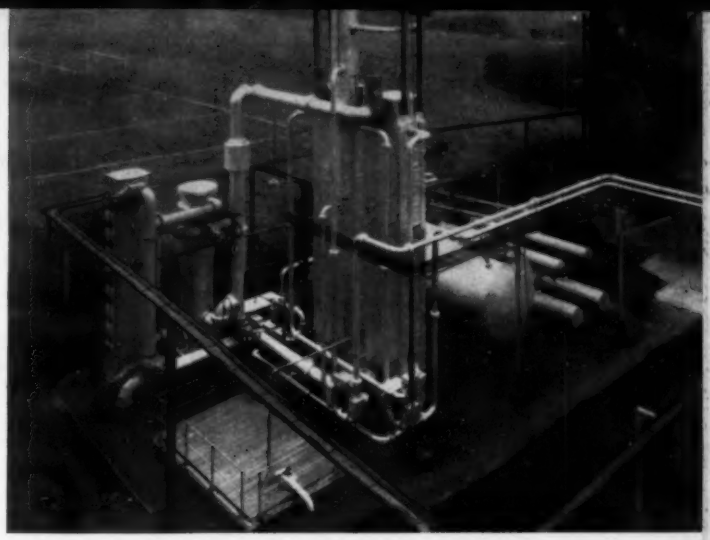


Fig. 1. The Lostock Hall gas dehydration plant. Capacity: 5 × 10^6 standard cu. ft per day.

NEW GAS DEHYDRATION PLANT USES REFRIGERATION

AT low-pressure gas plants the gas supply is dried by working with calcium chloride solution. In this country, during the winter months, this treatment is capable of reducing the dewpoint of the gases to 30°F or lower, whereas in summer the dewpoint may rise to 45-50°F. These levels of drying are satisfactory and are enough to prevent moisture from settling out in pipelines and equipment.

W. C. Holmes, who have designed and manufactured a large number of gas drying plants using calcium chloride solution, have recently put into operation a new type of plant, the first of its kind in this country, in which dehydration is achieved by refrigeration. This unit is installed at the Lostock Hall Works, Preston, of the North Western Gas Board, the gas plant in this case producing gas at a pressure of 10-16 psig. Since the Board have stipulated that a dewpoint of 37°F must be maintained throughout the year, the calcium chloride system could not be used and refrigeration was chosen as the most suitable alternative.

The main purpose of this plant was to dry the high-pressure supply boosted to Blackpool, but as it was not expected that boosting would be a continuous operation the plant was also designed to dry local low-pressure supplies as a secondary process. When high-pressure gas boosting is in operation, the refrigerated brine is used for the cooling of the high-pressure stream. Surplus chilled brine not required for the high-pressure stream is used to cool the local town gas supply. In this way, maximum use is made of the refrigerating plant capacity, and a useful degree of gas dehydration is maintained on local low-pressure supplies.

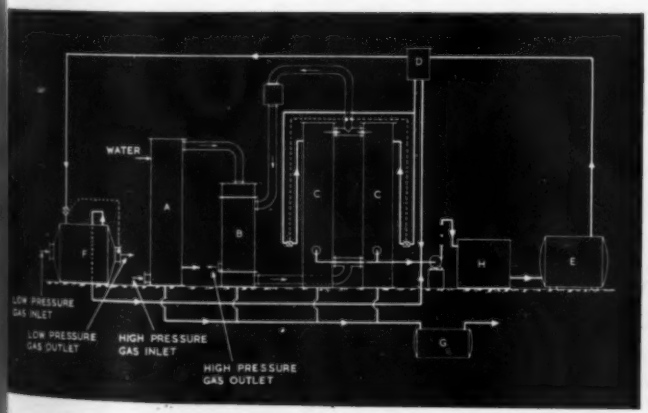


Fig. 2. Flow diagram of gas dehydration plant employing brine as coolant in the dehydrating cooler (C).

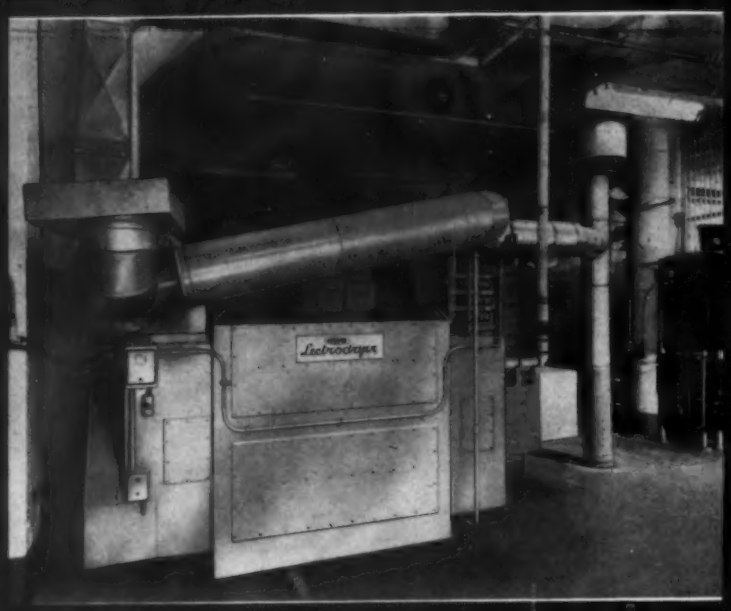
The plant has been designed to handle 5 million scfd of gas at pressures of 10-16 psig, and to chill the boosted gas to a dewpoint of 37°F at all times of the year. Dependent on the load and ambient temperatures, it can also produce an average reduction in dewpoint of approximately 6°F in the local low-pressure gas stream.

In operation, the high-pressure gas, at approximately 8-10 psig, passes through the after-cooler (A), where the heat of compression is removed. The gas is then cooled in a heat exchanger (B), with the final chilled gas before passing to the main cooler (C). The main cooler, which is of cross-tube design, is fed with chilled brine by way of a constant head pot (D) from a 6000-gal. chilled brine storage tank (E). The chilled gas passes through a mist catcher and finally cools the incoming gas.

Any surplus brine pumped up to the constant head pot and not required for high-pressure gas cooling is diverted to the low-pressure gas cooler (F). This cooler is also of cross-tube design and both coolers are fitted with condensate drains. The condensates from the high-pressure cooler, after-cooler and heat exchanger are collected in a condensate tank (G), which is emptied regularly, utilising the gas pressure to discharge the liquid.

The circulating brine is cooled in a standard ammonia-type refrigerating plant (H). This plant, together with the high-pressure coolers, brine circulating pumps and instrument air compressors, is supplied in duplicate to avoid any interruption to the process should mechanical troubles develop or when the plant is being serviced.

Dewpoints of the cooled gases are controlled by air-operated brine control valves, working in conjunction with cool gas temperature recorders and controllers. Cooling of the circulating brine is controlled by a thermostat located in the 6000-gal. brine storage tank. This tank, which is kept full, provides at least two hours' reserve of chilled brine when the refrigeration plant cuts out, thereby avoiding rapid on/off cycles. Cooled brine temperatures are generally between 30 and 35°F and at these temperatures there is no tendency for ice to form in the gas coolers. In practice, the plant has operated for several hours with the brine at 25°F without any increase in cooler back pressure, which suggests that no ice is formed at this temperature.



ADSORPTION DRYING OF GASES PART II

An introduction to the design of fixed bed adsorbers is preceded by a discussion on adsorbent characteristics

Moisture Adsorbents

BOTH activated alumina and silica gel consist of partially hydrated oxides formed by removal of water from the interstices of precipitated aluminium hydroxide and silicic acid. In each instance a strong and extremely porous solid remains with a wide range of pore sizes. Surface areas are quoted as approximately 250 sq. m./g. and 600 sq. m./g. respectively and 200 sq. m./g. for activated bauxite. Dehydration and activation are invariably heat-treatment processes and the effect of temperature on surface area, adsorption capacity and other properties of bauxite are given by La Lande *et al.*[57] Equilibrium curves for silica gel and activated alumina are given by a number of authors,[17, 29, 32, 56] in addition to the industrial manufacturers, showing wide variations in properties.

Recent work by Kiselev[43c] on the manufacture of silica gels provides evidence of the formation of small, approximately spherical, particles in the granules. The pores are then the space between these particles, which are in the range of 50-90 A° diameter, so that uniform pore silica gels could be modelled by pressed powders of non-porous spherical particles. Below the capillary condensation range the coincidence of Kiselev's isotherms of n-pentane plotted as quantity per unit surface area of adsorbent on quartz, Pyrex glass and wide pored silica gel shows the similarity of the attractive forces on each of these silicas. He suggests that for adsorption of the vapours studied, including water, these are due to hydrogen bonding with surface hydroxyl groups. Boer's[49b] investigations of the formation of the pore structure of activated alumina from its hydrates describes the mechanism of dehydration and the formation of the various crystal forms. As the lattice contracted, ruptures occurred at crystal planes giving fissure-like pores in the range 10-30 A° separated by rod or plate-like particles depending on the dehydration temperature. The adsorption bonds will be similar to those on silica gel and the isotherm of water on different samples of alumina shown as amount per unit surface area also showed coincidence up to the beginning of capillary condensation, at relative pressures above 0.50.

Molecular sieves used for water vapour adsorption are made by thermal dehydration of natural and synthetic zeolites.[59] Adsorption on the porous crystal structure that is obtained occurs within the crystal cages and the monolayer area is approximately 800 sq. m./g.[43d] The regular pore structure formed by the giant framework of giant alumina-silicate anions has windows giving access to the internal space whose dimensions are responsible for the molecular sieve properties. These and the adsorbent properties are influenced by cations such as Na, K and Ca that make up the structure. Equilibria data for water compared with silica and alumina type adsorbents is available.[59] Polar molecules such as water are very strongly adsorbed and, in addition to their higher capacity, molecular sieves have a lower rate of capacity decrease with temperature rise compared with the other adsorbents, impairing the performance less when used under adiabatic conditions. Above 550°C approximately the adsorptive properties of

molecular sieves may be destroyed because of crystal structure changes, and the equivalent temperatures for silica gel and activated alumina are respectively 300°C and 700°C. By choosing the appropriate molecular sieve adsorbent other gases in addition to water vapour may also be occluded—or excluded. The simultaneous removal of CO_2 or H_2S with water vapour is extremely useful for gas purification when the initial cost of this adsorbent cannot be otherwise justified. Steric factors become important as the size of the adsorbate molecule increases, when adsorption is either prevented or reduced to negligible proportions. This property is particularly attractive for dehydration of ethanol and methanol in the liquid phase because co-adsorption is prevented. The use of silica gel or activated alumina not only results in a reduced effective water capacity, but may result in appreciable losses during regeneration of the liquid filling the pores. Although these adsorbents will co-adsorb such vapours as NH_3, H_2S or CO_2 with water vapour, the capacities are usually too low to be useful.

These desiccants are available in granular or pelleted form and some of their properties are summarised in Table II.

When used in fixed beds for drying gases, these adsorbents provide a very high degree of moisture removal under suitable operating conditions. In the writer's experience, with such conditions, activated alumina and silica gel can produce consistent drynesses on an industrial scale of less than 1 ppm and 4 ppm by weight in air respectively while it is claimed[59] that molecular sieves will give less than 0.2 ppm. The adsorptive capacities, as indicated by adsorption isotherms, depend upon the source of manufacture and whilst it is desirable to take advantage of high values of this property, other factors, in addition to price, have also to be taken into account. These include reactivation and other energy requirements, the effect of contaminants, additional adsorbed vapours and useful desiccant life. This aspect is partly discussed by Amero *et al.*[60] and Hougen and Dodge.[61]

TABLE II.—Properties of Moisture Adsorbents

	Activated alumina	Silica gel	Molecular sieves
Bulk density, lb./cu. ft.	39–43	34–44	43–45
Specific heat, Btu/lb. °F.	0.21	0.22	0.25
Thermal conductivity, Btu/hr sq. ft °F in.	0·8	1·0	4·0
Mesh sizes available	2–4, 4–8, 8–16, 16–32	4–8, 8–16, 16–32	$\frac{1}{16}$-in. and $\frac{1}{8}$-in. pellets
	$\frac{1}{32}$-in., $\frac{1}{16}$-in. and $\frac{1}{8}$-in. pellets		

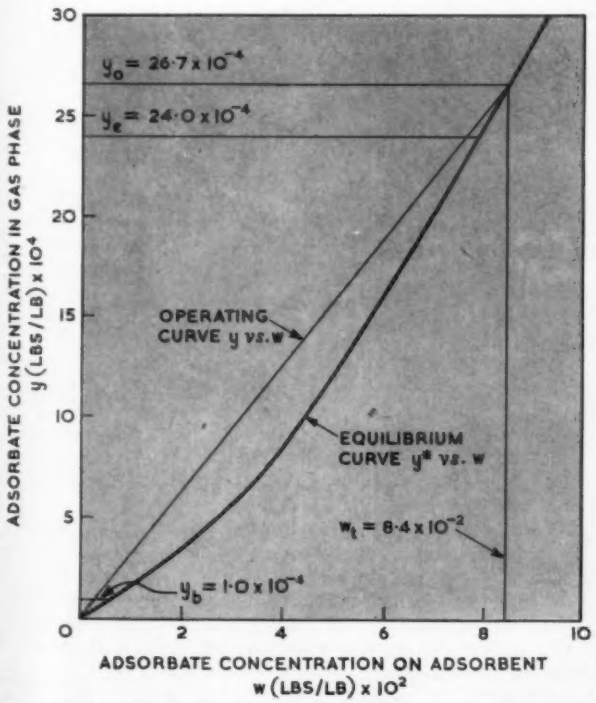


Fig. 4. Absorption isotherm for water vapour in air upon silica gel (Eagleton[65]).

Equipment and its Operation

In industry, granular and pelleted moisture adsorbents are normally used in fixed beds so that for continuous operation two or more operate cyclically.[62, 63] Automatic and hand-operated systems of changeover of a saturated adsorber to regeneration are both used so that cycle times in the latter instance usually fit in with shift times, allowing, say, 8 hours' adsorption per vessel. Although it is only on automatically operated plant that economic operation can be most easily attained, it is usual for the changeover signal to be time controlled on the smaller equipment perhaps with hand adjustment for longer cycles in winter. Very limited use is made of automatic humidity controllers at present, mainly because of price and restricted range at low humidities. However, the saving in regeneration power alone, by adjusting the length of the operating cycle, would justify their use in many instances, in addition to safeguarding the plant against breakdown and mal-operation.

The regeneration process consists essentially of supplying heat to desorb the water vapour with, preferably, the passage of an air or gas flow through the bed to remove the steam as it is formed. The method of heating may be the use of steam or electrically heated coils, or a flow of hot air or gas. If pipe coils are used, they may serve also as water cooling coils, but otherwise, if the bed dimensions are too large to allow natural cooling in the time available, it will be necessary to use a flow of cold dry air or gas. This can be made available by circulating the flow in a closed circuit through the adsorber and a cooler in series. With embedded heating coils, a large proportion of the heat is distributed by conduction so that the rate of heating is limited; when electric coils are used, high-temperature gradients and local overheating of the adsorbent can occur. If a vacuum is applied to remove the water vapour in such circumstances, condensation may occur in colder portions of the bed or on the vessel walls, and vitiate the subsequent gas drying performance. Using heated regeneration gas it is best to pass it through the bed in the reverse direction to the adsorption flow to ensure that the dry gas outlet side is fully reactivated; any temperature gradient, which is difficult to avoid, then falls towards the adsorption inlet end. Should the heated flow be passed in the same direction as during adsorption, it is necessary to thoroughly heat the adsorbent throughout, since water vapour evaporated at one end will be partially re-adsorbed in colder portions until they are also heated. It is not unknown, at the beginning of the drying cycle, for the exit humidity to be relatively high because of well-dried gas evaporating moisture from a less well-regenerated portion of the desiccant at the other end. It is also necessary to thoroughly heat the outlet pipe and portions of the vessel that have been in contact with the moist reactivation flow, if high drying efficiencies are required, since moisture is occluded by surface oxides. The use of unheated purge gas in the reverse direction to adsorption, when embedded heating coils are used, may easily keep the "dry gas" end of the bed cold and also partially saturate it if the gas is not predried, again causing a "wet shot" at the beginning of the adsorption period.

Both fluidised and moving bed adsorption dryers have been built, but few, if any, are now in use. Certainly, where

very large gas flows have to be treated, particularly at near atmospheric pressure, the sizes of the changeover valves and manifolds needed for cyclic operation make these alternative methods attractive, in addition to the possibilities of heat recuperation not available in the cyclic process. However, for reasonable adsorption efficiency, the fluidised system needs a multistage gas-solids counter-current contacting system.

Design of Fixed-bed Adsorbers

Although the most important problem in designing adsorption equipment is that of deciding on the amount of adsorbent, the design of the plant as a whole is the common one of engineering economics. Reducing the incoming solvent vapour concentration in air may not only be necessary to prevent the formation of an explosive mixture, but also to prevent high temperature rises due to the heat of adsorption which might seriously affect the capacity. However, the decrease in adsorber dimensions has to be economically balanced against the increased power requirements for the diluting air, bearing in mind also the possibility of reduced adsorptive capacity because of the lower partial pressure if dilution is carried too far. Higher temperature rises can occur in adsorber beds when drying air because of the high heat of adsorption of water vapour, so that the cost of precooling, possibly using refrigeration, and perhaps increased pressure drop has to be balanced against the lower capital and regeneration costs of the adsorption plant. Reactivation requirements can vary from at least one to five or more kWh per lb. of moisture removed, depending on the duty required and the design of the equipment.

Because of the shortage of published information on the performance of packed adsorption beds, evaluating the many variables such as inlet concentration, temperature, flowrate, adsorbed and adsorbent properties, it is understandable that in the majority of cases prediction of performance is based on small-scale tests. These simulate the large-scale conditions as nearly as possible and are backed by experience of equipment already in operation. This empirical approach can be restrictive when catering for unusual conditions of operation, easily leading to overdesign, and an excessively large number of tests would be necessary to determine completely the effect of each variable. It is proposed to illustrate that the analytical and more rigorous method of dealing with the transient operations in an adsorption bed enables reasonably accurate prediction of performance to be made.

By considering the mass balance of adsorbate in an inert gas flowing through a packed bed of adsorbent granules, Rosen[18] has derived the following equation of conservation across an element of differential height dz, assuming no radial concentration gradients.

$$v\,(\partial c/\partial z) + \partial c/\partial t - D_L\,(\partial^2 c/\partial z^2) = -\,(\partial q/\partial t)\,.\,1/m$$

v = linear flow velocity (ft/sec.);
c = concentration of adsorbate in gas (volumetric or molar);
q = average concentration of adsorbate on adsorbent granules (volumetric);
m = void volume per unit volume of adsorbent (dimensionless);
t = time (sec.);
D_L = longitudinal diffusion coefficient (sq. ft/sec.); and
z = height of bed (ft).

Longitudinal diffusion in the gas phase is usually neglected, since the value of $D_L\,(\partial^2 c/\partial z^2)$ is considerably less than $v(\partial c/\partial z)$ under normal flow conditions.

Transfer through the boundary layer to the surface of the granules is described by

$$\partial q/\partial t = 3h/b\,(c - c^*) = 1/R_f\,(c - c^*)$$

and then in the granules by

$$\partial q_i/\partial t = (D/r^2)\partial/\partial\, r[r^2\,(\partial q_i/\partial r)]$$

h = gas film mass transfer coefficient (ft/sec.);
b = effective radius of granular particles (ft);
c^* = concentration of adsorbate in gas in equilibrium with adsorbate concentration at granule surface (volumetric);
q_i = concentration of adsorbate in granules at radius r (volumetric);
r = radial distance from centre of granule (ft);
D = effective solid diffusion coefficient in the granules (sq. ft/sec.); and
R_f = effective surface film resistance (sec.) = $b/3h$.

In conjunction with these equations, Rosen considered the simplest form of equilibrium relationship in the form of Henry's law.

$q_e = Kc^*$
K = Henry's law constant; and
q_e = adsorbate concentration on granule surface (volumetric) (in equilibrium with c^*).

Thus $\partial q/\partial t = 3h/b\,(c - q_e/K) = (D/b^2)\,\partial/\partial r[b^2(\partial q_i/\partial r)]$
Also, the average concentration in the particles, q, is related to the internal concentration q_i at radius r by:

$$q = 3/b^3 \int_0^b q_i r^2 dr$$

Rosen has solved these equations for the initial state of an adsorbate free column, giving effluent concentration as a function of time and bed length, following a step increase in the influent concentration from zero to c_0 at $t = 0$. The solution is based on the assumption that the gas film and solid diffusion coefficients are independent of position in the bed and vapour concentration. Its form is dependent on three dimensionless parameters, proportional to the surface film resistance, effective bed length and time of contact, in addition to the solid diffusion coefficient in each case.

$$u = c/c_0 = 1/2 + \Psi(V, x, y)$$

where $V = 3DKR_f/b^2$ = film resistance parameter (dimensionless);
$x = 3DKz/mvb^3$ = bed length parameter (dimensionless);
$y = 2D(t - z/v)/b^2$ = contact time parameter (dimensionless); and

$$\Psi(V,x,y) = \int_0^\infty e^{-xH_1\beta^{\frac{1}{2}}V} \sin\,[y\beta - xH_2\beta^{\frac{1}{2}}V]/\beta.\; d\beta$$

The functions H_1 and H_2 are defined in Rosen's paper.[18] Fortunately, using a digital computer, he has evaluated the integral for a range of numerical values of V, x and y giving u both graphically and in tabular form against values of the dimensionless parameters. These curves are similar to those of Schuman and Furnas[64] for heat transfer in packed beds. He also gives simpler solutions for limiting cases, notably for large values of the bed length parameter and for negligible gas film resistance, which only need a table of error functions for their evaluation. So far no application appears to have been made of this analysis to experimental results of vapour adsorption and examples of its use will be given later predicting the performance of silica gel and alumina dryers.

Rosen's treatment of mass transfer in a packed column makes reasonable simplifications by ignoring longitudinal diffusion and neglecting the kinetics of adsorption. Hougen and Marshall[19] further simplified this picture, by assuming that the concentration difference across the fluid boundary layer is a function of the average concentration in the solid and not the surface value. This means that mass transfer across the fluid film is controlling and the effect of solid diffusion is negligible. In addition, they assume that the quantity of vapour in the gas phase in the interstices of

the bed is small compared with the total amount involved, giving the following mass balance and rate equation

$$-G\,(\partial y/\partial z) = \rho_B\,(\partial w/\partial t) = k_g a\,(y - y^*)$$

the linear equilibrium relationship being

$$y^* = C\,.\,w$$

where G = mass velocity (lb./hr sq. ft);
y = adsorbate concentration in the gas (lb./lb.);
y^* = concentration in equilibrium with w;
w = average adsorbate concentration in solid (lb./lb.);
ρ_B = bed bulk density (lb./cu. ft);
a = external area of adsorbent particles (sq. ft/cu. ft);
k_g = mass transfer coefficient defined by above equation;
C = Henry's Law constant
z and t have been defined previously.

The terms used in these equations have the same dimensions as in Hougen and Marshall's paper[17]; transcription to those of Rosen or vice versa would complicate the use of each author's solutions and is unnecessary.

The solution to the above equation gives the outlet concentration as a time and bed depth dependent variable, for an influent concentration y_0 at $t = 0$, using dimensionless thickness and time moduli.

$$u = y/y_0 = 1 - e^{-bt}\int_0^{gz} e^{-gz}\,J_0\,(2i\sqrt{bt\,.\,gz})\,d\,(gz)$$

where $g = \dfrac{G}{k_g a} = \dfrac{1}{H_{tog}}$ and gz = thickness modulus [dimensionless];
H_{tog} = Htu based on overall gas film;
$b = \beta C : \beta = \dfrac{G}{\rho_B H_{tog}}$ and bt = time modulus (dimensionless); and
$i = \sqrt{-1}$: J_0 = Bessel function of the first kind and zero order.

The equation has been evaluated and plotted by the authors as Schuman-Furnas curves, of u against the time modulus with the thickness modulus as parameter. Hougen and Marshall also give the equation below relating the overall height of a transfer unit, based on the gas film, to flow rate and particle size, calculated from Ahlberg's data adsorbing water vapour from air passing through thin beds of silica gel.

$$H_{tog} = \frac{1.42}{a}\left(\frac{d_p G}{\mu}\right)^{0.51}$$

d_p = particle diameter (ft); and
μ = gas viscosity (absolute).

This is used by them to illustrate examples of calculation of vapour adsorption in fixed beds of silica gel.

An alternative approach by Eagleton and Bliss[17] allows for the concentration gradient in the adsorbent by means of a hypothetical solid film coefficient, so that the conservation and rate equations now become

$$-G\,(\partial y/\partial z) = \rho_B\,(\partial w/\partial t) = k_g\,.\,a(y - y_s) = k_s\,.\,a(w_s - w)$$

where k_g and k_s = the gas and solid film mass transfer coefficients defined by the equation;
y_s = gas phase concentration at solid surface (lb./lb.) in equilibrium with w_s; and
w_s = solid phase concentration at solid surface (lb./lb.).

Eagleton's approximation of his isotherm which was concave to the gas concentration axis is a straight line not passing through the zero.

$$w_s = A + B\,.\,y_s$$

where A = the intercept of the straight line with the solid phase composition axis; and
B = the slope of this line.

His solution, relating outlet concentration with the quantity of gas that has passed through the bed, is in two parts and is based on a constant adsorption band width as it moves along the column. The first part applies up to the value $q_s = A$ when back pressure from the adsorbed vapour is considered negligible, and the second when y_s cannot be neglected. Eagleton compares his calculated and experimental results for water vapour adsorbed from an airflow, passing through columns of silica gel and activated alumina. The accuracy of his predictions are by no means consistent. His data correlate as follows the gas and solid film coefficients for the adsorbent particles in the size range used.

Activated alumina: $k_g a = 476\,G^{0.55}$ lb./hr cu. ft.
Silica gel: $k_g a = 188\,G^{0.55}$ „
Activated alumina and silica gel: $k_s a = 217$ lb./hr cu. ft.

It is interesting to compare the Htu based on the gas film for these two adsorbents with that derived by Hougen and Marshall based on the overall gas film. For the alumina and silica gel used they are respectively

$$\frac{2.02}{a}\left(\frac{dG}{\mu}\right)^{0.45} \text{ and } \frac{1.05}{a}\left(\frac{dG}{\mu}\right)^{0.45}.$$

Treybal[3] uses one of the experimental runs to illustrate Michael's graphical method for adsorption in a fixed bed. This also assumes a constant shape adsorption band, which is presumed to remain stationary while the solids bed moves at a rate to ensure this. It is then possible to construct an operating line and, using the actual isotherm, the mean concentration driving force is derived graphically to give the number of transfer units in the adsorption band. This example is compared later in this paper with calculations based on both Rosen's and Hougen and Marshall's method, but reference should be made to Treybal for further details.

Houghen and Marshall point out that the Htu values calculated from Ahlberg's data are 3-4 times greater than those based on the gas film only over a wetted surface. It is thus apparent that transport of adsorbate in the granules cannot always be neglected, and that the total resistance is compounded from a gas film coefficient and a measurable resistance to flow in the adsorbent. The relative importance will depend upon the operating conditions, but data published by Foster and Daniels,[65] for adsorption of nitrogen peroxide on silica gel, also supports the existence of measurable resistance to transport in the granules. Eagleton and Bliss state that both the gas and solid film coefficients show considerable dispersion. Also the former are 25-50% less than those based on j_d factors for conditions in which a gas film alone is operative. This is quite probably due to an incorrect value of the interfacial concentration determined by this method, and confirms that diffusion into a sphere can only be very approximately described by the linear relationship used. It is most unlikely that the solid film coefficient would be the same for the adsorbents investigated, and also invariant over the range of concentration that occurs. Needless to say, incorporating the solid phase resistance, which will be mainly a function of concentration and independent of the gas flow rate, with the gas film resistance in an overall transfer coefficient dependent on flow rate only, as Hougen and Marshall have done, is an even greater approximation. The assumption of constant adsorption band width is no doubt justifiable for operating conditions where the wave has time to establish itself as in Eagleton's experiments, and where the isotherm has self-sharpening characteristics, i.e., is concave to the gas phase concentration axis. However, for high flow rates and comparatively shallow beds, it will not necessarily apply.

ERRATUM

Nomogram No. 49, p. 512 (July): the equation for the multiplying factor should read $F = 1 + 3.5\,\dfrac{d_t}{d_c}$.

664.25

CHEMICAL ENGINEERING IN MAIZE PROCESSING

In a rapidly developing plant on the banks of the Manchester Ship Canal maize is processed to pure starch, glucose, dextrines, animal feed, speciality starches and other products

FROM a small glucose refinery in the Trafford Park industrial estate, Manchester, Brown & Polson Ltd. has built up the largest maize-processing factory in Europe. At a private wharf, ocean-going ships carrying 9000 tons of maize are unloaded pneumatically and the raw material stored in concrete silos. The maize kernel is separated into its constituents, starch, germ, protein or gluten, and husk or fibre. Starch, forming 70% of the original kernel, constitutes the major process stream. A large proportion of it is later converted into liquid glucose, corn sugars and a wide range of starch specialities.

Materials flow can be seen in Fig. 3. As required, the shelled maize is drawn from the silos on to a conveyor, weighed and then cleaned by air blasts, sieves and magnets to remove fines, husks and foreign matter. The raw material is slurried in process water to the wet mill and steeped in water at 124°F for 40 hr, a process which softens the kernels so that the germ can be removed easily. Steeping is carried out in a series of concrete tanks, tile lined and fitted with wooden strainers at the base. Steep water passes through the tanks in series, the fresh water meeting the corn which has been steeped for the longest time. To prevent bacterial growth and control lactic acid formation, sulphur dioxide is added to the steep water: the SO_2 is made on site in direct sulphur burners.

The softened corn is then subjected to carefully controlled milling operations. In the first, Foos mills, the kernel is simply broken open so that the germ is exposed. After the germ has been removed the remainder of the kernel is more thoroughly ground, to free the starch, gluten and fibre.

Germ separation takes place in tile-lined settling tanks where the oil-containing germ floats over a weir and the remainder is screw conveyed from the base. To reduce the load on the final grinding mills, free starch and gluten are removed on Contessor machines—centrifugal filters with a perforated conical basket revolving at 3000 rpm and a screw turning at a slightly different speed to remove solid matter continuously. Fibre is eliminated by reels, trommel-type machines fitted with fine nylon cloth.

The two remaining constituents of the maize, the starch and the gluten, are separated on stainless-steel De-Laval disc centrifuges. Starch containing 4½% gluten then goes forward to a bank of nine Dorr-Oliver hydroclones where all the process water for the wet mill enters as fresh water

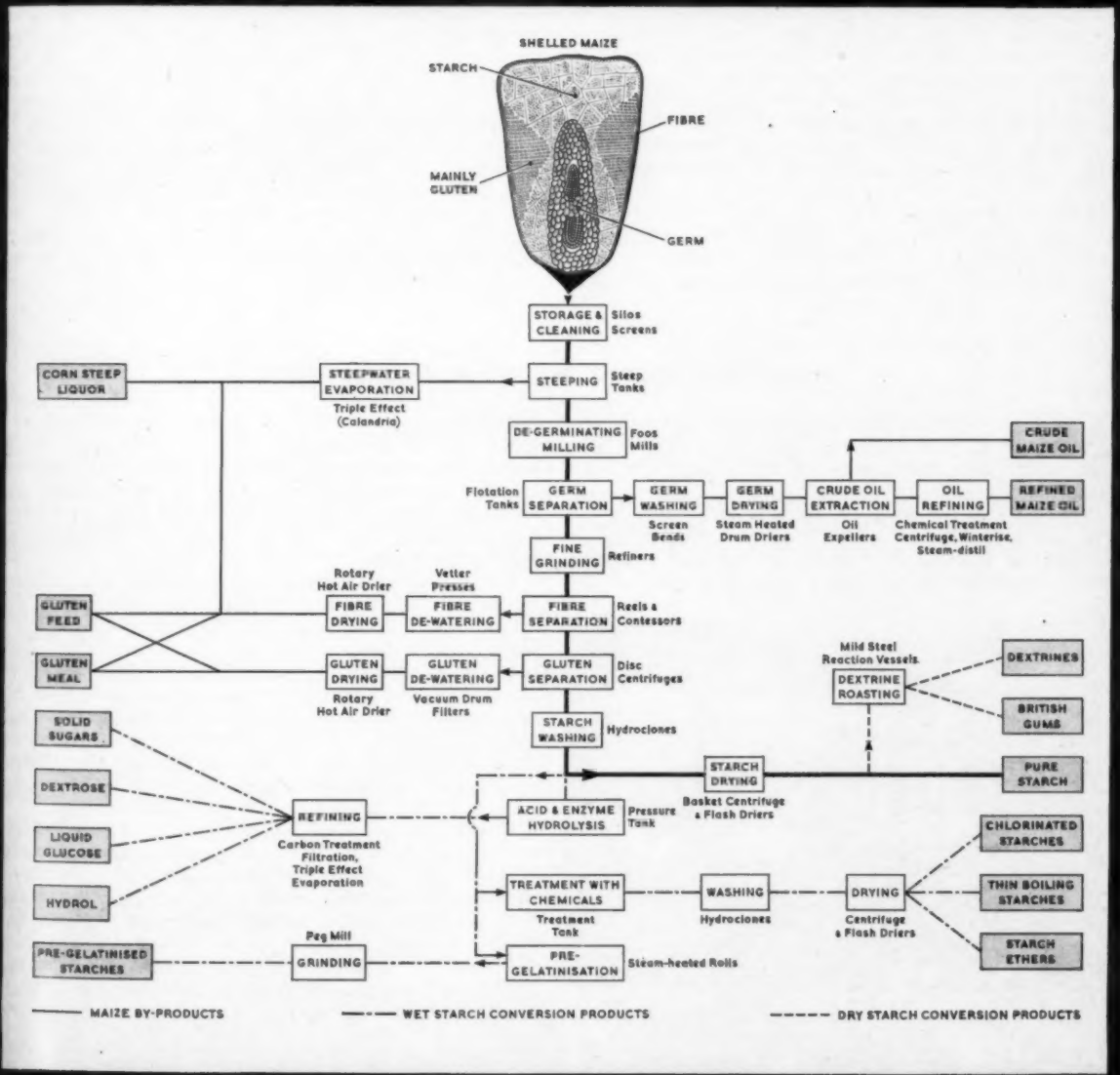
and washes the starch counter-currently. These Dorrclones are the first to be used in Britain for this purpose, and give a very pure starch product. Gluten, from the primary De-Lavals and the Dorrclones, is concentrated in QX-type De-Laval centrifuges. Separation efficiency in all these machines is tested by spinning samples in a laboratory tube centrifuge: yellow gluten can be readily seen against the white starch layer.

Starch leaves the wet mill as a water slurry and passes in this form to the manufacturing division which can use it. Material which is required dry for further processing, or which is sold directly for food manufacture or corrugating adhesive, passes through an automatically cycling, horizontal, perforated bowl centrifuge and then to hot-air flash driers—60-ft vertical tubes up which flow the starch and air to separating cyclones. Dry starch is either bagged or pneumatically conveyed to bulk handling wagons.

Maize By-products

All parts of the maize kernel are used. The germ taken off in the germ separating tanks is first partially dewatered in screen bends, followed by Vetter presses, and finally taken down to 2% moisture in steam-heated rotary drum driers. In heated oil expellers, the maize oil is mechanically squeezed out of the germ, leaving a cake containing about 8% of oil which is used for animal feed. After filtration the maize oil may be sold as a crude oil for subsequent margarine production, or further refined to give a pure oil for cooking.

Fibrous material leaving the wet mill at 90% moisture content is partially dewatered in Contessor machines and then dried further in Vetter presses. Final drying is effected in direct oil-fired rotary drum driers. Gluten from the wet mill is recovered on string discharge, rotary vacuum drum filters and finally dried in another direct oil-fired rotary



drum drier. Fibre and gluten are blended to give animal feeds varying in the protein content. Spent liquor from the steep tanks is concentrated in triple-effect evaporators and sold as corn steep liquor for antibiotic manufacture or added to the animal feed to bring up the protein content.

Liquid Glucose and Sugars

A high proportion of the starch is hydrolysed with acid, and enzymes in certain cases, to give liquid glucose and solid corn sugars. Starch slurry of the correct specific gravity is subjected to pressure and temperature in converters until tests show the required amount of reducing sugars to be present. Refining processes similar to those used in the sucrose industries are then applied. First the liquors from the converters are filtered on rotary pre-coat filters and then passed through Vallez filters which have carbon on their leaves from earlier batches. After concentration in triple-effect evaporators, carbon is added to the liquor and then removed in a clean Vallez filter. The carbon left on the leaves is exhausted on the next batch of liquor. Final concentration is carried out in a Kestner pan or a climbing film evaporator.

At this stage liquid glucose is the main product. It is processed to give a desired specific gravity and reducing sugar content according to the requirements of the customer.

Converted and refined syrup containing a high proportion of reducing sugars is placed in large water-cooled crystallisers to bring down pure dextrose crystals. These are removed and washed in perforated basket centrifuges and then dried in hot-air drum driers before bagging off. Mother liquor from the crystallisers and other highly converted syrups are allowed to set in trays to give blocks of corn sugars. These are pulverised and sieved before bagging.

Speciality Starches

Maize starch has its own particular cooking qualities: a slurry in water which is heated above gelatinisation temperature and then cooled gives a paste which gradually "thickens", that is, becomes more viscous on standing. Chemical treatment is used to give starch products with different cooking qualities. Starch slurry is heated in large concrete tile-lined tanks with acid, alkali, hypochlorite or propylene oxide to give thin-boiling starches, starch ethers, chlorinated and other starches, each of which has characteristic properties. For example, starch treated with acid is known as a thin-boiling starch because a cooked slurry of given concentration is less viscous than a maize starch cooked at the same concentration. The gel formed on cooling is harder and so suitable for certain confectionery products. After chemical treatment each starch product is washed in a hydroclone system to remove cold-water-soluble material, centrifuged in an automatic-cycling, perforated basket centrifuge and then dried in a hot-air flash drier.

Some maize starch is pre-gelatinised; it is pre-cooked so that it will form a paste in cold water. Starch slurry is passed on to steam-heated rolls, cooked and dried. A film of dry product is picked off with a doctor knife, ground and bagged. This material is the base for cold-water-soluble "instant" foods, wallpaper pastes and other products.

Dextrines

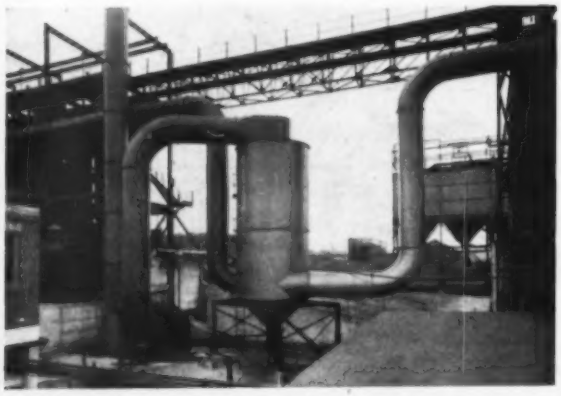
By heating acidified, dry starch it is possible to modify its cooking characteristics in a different way. This process gives dextrines and British gums, products used in adhesives, textile sizing and finishing, and foundry binders. In the processing dry starch is placed into horizontal wooden drums and acidified with a mist of HCl. Then it is dropped into steam-heated "roasters" and subjected to a carefully controlled temperature cycle which breaks the starch molecules to the desired degree. Finished material is dropped into coolers and finally blended and sieved before bagging off.

This factory produces industrial products in bulk: the same company's original factory at Paisley, now greatly expanded and modernised, produces the more widely known domestic products.

Problem Solved by Fuel Producers

MANUFACTURERS of smokeless fuel have for a long time been receiving complaints from local authorities and residents that their plants are creating too much smoke and dust.

Now, one of the leading smokeless fuel producers, the National Carbonising Co. Ltd., has solved the problem by installing a specially designed smoke and dust extraction plant at their Edwinstowe works. This plant, known as the Holmes-Schneible multi-wash system, was designed and installed by W. C. Holmes & Co. Ltd. to the order of the main contractor, Newton, Chambers & Co. Ltd. It was installed following extensions to the low-temperature carbonisation plant to double production of Rexco smokeless fuel. The plant now comprises 14 retorts each capable of holding 34 tons of coal.



The National Carbonising Co. Ltd.'s new smoke and dust extraction plant at Edwinstowe, Notts.

The base of each retort is enclosed by an exhaust hood which prevents the escape of dust and raw gas when the retorts are discharged. A considerable amount of steam from the quenching water is exhausted at the same time. Two branch connections from each exhaust hood connect with the main duct which runs along the complete length of the retort installation. As there are only two branches out of the total of 28 in operation at any one time, specially designed dampers were made to ensure that the branches are virtually airtight in order that the maximum percentage of the total gas volume is exhausted from the hood in operation.

The Holmes-Schneible collector is a size 124 type "JC" and contains two and a half impingement or washing stages. It is positioned mid-way between two banks of seven retorts and for this reason has two inlets. The fan is installed on the clean gas side of the collector and handles 34,000 cfm against the system resistance of 8 in. s.w.g. It absorbs 56.6 hp from the 60-hp driving motor. The washing medium is recirculated from a concrete effluent tank. This equipment will, it is hoped, completely solve the company's dust and smoke problem.

PERFORMANCE OF PLATE HEAT EXCHANGERS

Results obtained from a corrugated plate exchanger in operation at a Russian sulphite pulp plant

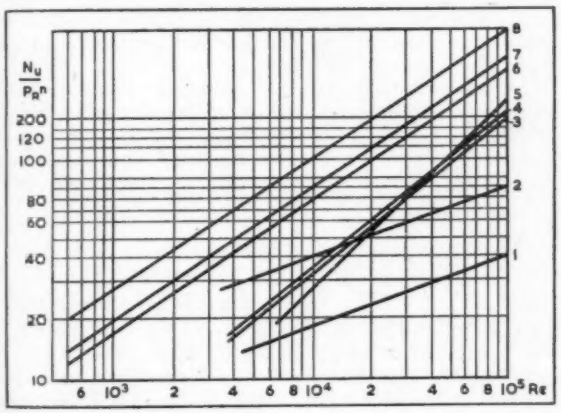


Fig. 1. Heat transfer for turbulent flow of liquids in various types of heat exchanger.

1 and 2, Slot-like, corrugated channels. 3, Straight tubes. 4, Straight narrow channels. 5, Spiral heat exchangers. 6, Laval-type plate exchanger. 7 and 8, Plate heat exchangers with corrugated channels.

PLATE heat exchangers are now widely used in industry on account of their high efficiency, compactness, ease of cleaning and maintenance. However, little has appeared in the literature on the design of this equipment, one of the few examples being a paper by Parker.[1]

A recent publication[2] gives details of heat-transfer performance for liquids in plate heat exchangers employing a plate of the profile shown in Fig. 2. In exchangers of this kind, owing to the numerous changes in direction and cross-section, there is an extensive exchange of heat and mechanical energy, the latter being accompanied by increased hydraulic resistance. Turbulent flow appears to be established for Reynolds numbers at about 200 and in a few cases at 500, compared with 2300 for straight channels and 14,000 for spiral tubes.

Operating data for different types of exchanger are given in Fig. 1, from which it is clear that the heat-transfer rates are appreciably higher in plate exchangers than in other types under comparable conditions. For example, if the value of h for coils is unity at a Reynolds number of 10,000, then for straight channels $h = 1.45$, for slot corrugated channels $h = 1.5$ and for plate exchangers with corrugated channels $h = 2.9$ to 3.2. When the Reynolds number

Performance Data for a Plate Heat Exchanger

Number of run	Acid							Water							Total heat transferred, kcal/hr	Film-heat transfer coefficient	
	Flow velocity, m/sec	Inlet temperature, °C	Outlet temperature, °C	Pressure drop kg/sq. cm	Reynolds Number	Prandtl Number	Film-heat transfer coefficient, kcal/sq.m. hr °C	Flow velocity, m/sec.	Inlet temperature, °C	Outlet temperature, °C	Pressure drop kg/sq. cm	Reynolds Number	Prandtl Number	Film-heat transfer coefficient, kcal/sq. m. hr °C		From heat balance kcal/sq. m. hr °C.	From equation obtained kcal/sq. m. hr °C.
1	0.88	17.4	64.8	1.60	12830	4.22	9140	0.99	77.0	30.2	1.50	17680	3.33	9320	$3725 \cdot 10^3$	2980	3040
2	0.88	17.6	63.6	1.45	12730	4.26	9120	0.91	76.2	29.2	1.50	15850	3.38	8720	$3614 \cdot 10^3$	2990	2970
3	0.81	17.5	61.1	1.45	11350	4.38	8530	0.84	72.2	28.4	1.20	14230	3.52	8180	$3131 \cdot 10^3$	2850	2840
4	0.76	17.4	60.4	1.35	10540	4.42	8150	0.79	71.0	27.8	1.10	13140	3.58	7810	$2896 \cdot 10^3$	2760	2760
5	0.68	17.4	60.9	1.40	9570	4.40	7650	0.75	69.9	28.4	1.00	12420	3.61	7530	$2645 \cdot 10^3$	2640	2590
6	0.72	14.0	60.5	1.20	9630	4.61	7790	0.74	71.6	24.8	1.00	12160	3.67	7450	$2963 \cdot 10^3$	2710	2670
7	0·65	14.0	60.8	0.80	8740	4.59	7310	0.68	70.4	24.0	1.00	10940	3.75	6980	$2995 \cdot 10^3$	2750	2550
8	0.60	14.2	59.7	0.80	7950	4.64	6890	0.62	69.8	23.9	0.70	9830	3.78	6610	$2411 \cdot 10^3$	2430	2450
9	0.53	14.3	59.4	0.65	7110	4.65	6420	0.54	69.3	23.0	0.60	8550	3.83	5970	$2140 \cdot 10^3$	2300	2300
10	0.47	14.3	58.9	0.60	6250	4.67	5900	0.47	68.6	22.2	0.55	7350	3.89	5430	$1868 \cdot 10^3$	2120	2150
11	0.34	14.4	60.0	0.45	5210	4.61	5220	0.41	67.9	22.5	0.45	6320	3.90	4930	$1575 \cdot 10^3$	1970	1950
12	0.34	14.5	58.6	0.35	4470	4.69	4760	0.34	66.9	21.0	0.30	5150	4.00	4330	$1387 \cdot 10^3$	1790	1810
13	0.27	14.5	59.2	0.30	3540	4.65	4080	0.28	65.7	21.4	0.30	4210	4.03	3810	$1055 \cdot 10^3$	1580	1610
14	0.22	14.5	53.9	0.25	2730	4.94	3500	0.20	63.2	18.2	0.20	2780	4.28	2940	$758 \cdot 10^3$	1250	1350
15	0.22	14.5	53.9	0.20	2750	4.95	3520	0.20	63.2	17.9	0.20	2770	4.29	2930	$763 \cdot 10^3$	1300	1360

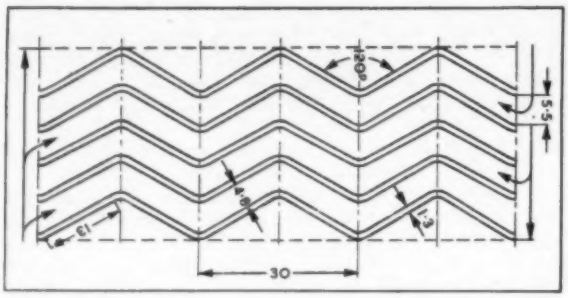


Fig. 2. Profile of the channels of plate heat exchanger used in tests.

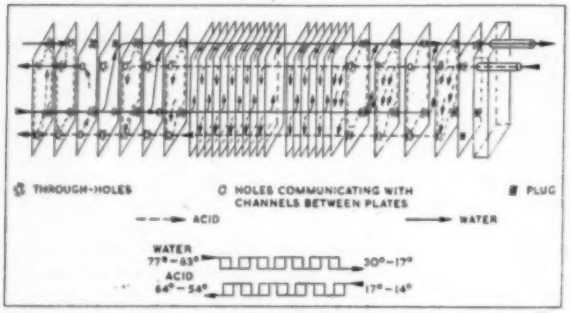


Fig. 3. Flow arrangement of plate heat exchanger used for cooling acid.

is below 10,000 the superiority of the plate exchanger is even more marked.

The tests reported relate to an exchanger with a surface of 100 sq. m. It was used to heat process acid with water as a stage in the production of sulphite pulp. The exchanger had 191 plates 1.37 m. × 0.5 m. The plates were 1.5 mm in thickness and the distance between surfaces was 5.5 mm. The exchanger consisted of seven sections connected in series with each section containing 13-14 parallel channels as shown in Fig. 2. The flow arrangements are shown in Fig. 3.

In the tests Reynolds number varied from 2500 to 18,000 and the Prandtl number from 3.3 to 4.9. Water was cooled from 77 to 17°C and the acid raised in temperature from 14 to 64°C. This range of temperature was dictated by the process. The measurement of the temperatures of the two media was made at inlet and outlet of the apparatus, likewise the corresponding pressures. The precision of measurement was good enough to give values of the heat-transfer coefficient to an accuracy of $\pm 4.6\%$.

The experimental results were compared with the conventional equation for heat transmission in turbulent flow

$$Nu = A\ Re^m\ Pr^n \qquad \ldots . (1)$$

and the task was therefore to find suitable values for the coefficient A and the power of m in this equation. In the relationship obtained, the temperature of the metal surface is neglected; m was found $= 0.65$ and the constant $A = 0.189$. With these values the divergence between experimental and calculated results was not greater than 5 to 8%. The final equation was thus

$$Nu = 0.189\ .\ Re^{0.65}\ Pr^n \qquad \ldots . (2)$$

where the Prandtl number exponent is 0.4 or 0.3 depending upon the direction of heat flow.

The velocities of flow for both acid and water were 0.9 to 1 m./sec. and film heat-transfer coefficients greater than 9000 kcal/sq. m. hr °C were obtained for the acid and in excess of 10,000 in the case of water. The overall coefficients found in practice ranged from 1400 to greater than 3000.

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[2] Ginstling, A. N., and Barsov, B. V. *Khim. Mashinostr.*, 1959, **6**, 20.

Exhibition in Moscow

Mr. Khruschov, showing a keen interest in exhibits at the I.C.I. Plastics Division exhibition which was held at the Polytechnical Museum, Moscow, in June.

ON THURSDAY, June 2, Mr. Khruschov, the Soviet Prime Minister, accompanied by half the Praesidium Central Committee, visited the I.C.I. Plastics Division exhibition at the Polytechnical Museum, Moscow, Mr. Khruschov said that he welcomed this kind of informative exhibition and wished it every success.

The exhibition, which has attracted great interest, has been packed all the time, and people had to be let through in relays so that they would have a chance to see all the displays. They were able to put questions to the many Russian-speaking guides, who were pleased to answer all queries. Seven and a half tons of printed publicity material were available, but the demand was so great that after the first five days of the exhibition distribution had to be severely rationed.

Despite their highly technical nature, all of the lectures were fully attended and more questions were handed in at each session than could be handled. Each was well illustrated with films and slides, and lectures were translated immediately by Soviet interpreters. It is a pity that only one of the films was dubbed with a Russian sound track.

Amongst the exhibits were a motor boat made from "Alkathene", an Austin Seven saloon car showing the uses of I.C.I. plastics in the motor industry, sections of bathroom and kitchen featuring "Perspex" sanitary ware, and p.v.c. flooring, large rigid p.v.c. tubing and p.v.c. conveyor belting for foodstuffs and coal.

The exhibition will be open in Leningrad from July 15 to 29 and its continued success is already assured.

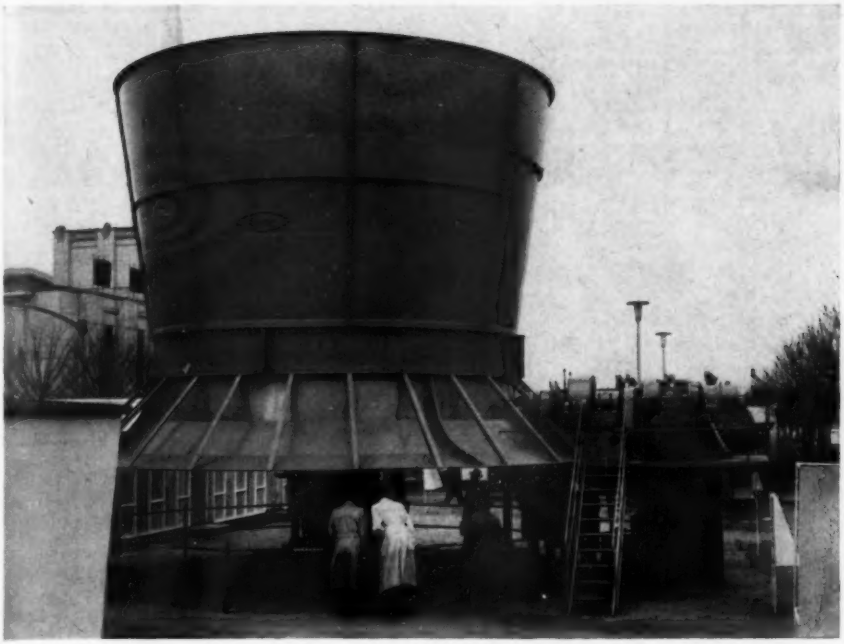

Fig. 1. Cooling tower axial-flow fan by VEB Maschinenfabrik NEMA. Air throughput 1½ million cu. m/hr.

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THE LEIPZIG TRADE FAIR PART II

Tape-wound Pressure Vessels

Tape-wound pressure vessels were shown by two exhibitors, one from West Germany, Phoenix Rheinrohr AG, and VEB Maschinenfabrik Germania, of East Germany. In each case the tape profile used was similar as were the dimensions of vessels. Phoenix Rheinrohr supply them in internal diameters up to 1.5 m, in lengths of 20 m and for working pressures up to and in excess of 1000 atm. VEB Maschinenfabrik Germania offer vessels of 0.8 to 1.2 m i.d. and 18 m long for working pressures up to 325 atm (Fig. 9).

Spirally welded tubing was shown by two West German firms, Grossrohrwerk Salzgitter Stahlbau G.m.b.H. and Hoesch A.G. Rohrwerke. The range of sizes in which such pipe can be supplied is much the same for each firm, ranging from 0.6 m to 1.6 m diameter, with 6 to 16 mm wall thickness, in lengths up to 15 m. Such piping fabricated from best quality carbon steel and air-refined steels has a number of advantages over shells employing in their fabrication longitudinal and circumferential welded seams. It is, for example, almost perfectly round, the interior surface is excellent, and since under internal pressure the helically welded seam is subjected only to a component of the force acting upon the pipe material, thinner walls are permissible without sacrifice of safety. So far no one appears to have produced such pipe in special alloys, although several firms are known to be investigating this idea, which has considerable attractions to the chemical plant fabricator.

Drying Equipment

Driers were well represented, and at least four concerns showed either spray driers, or important parts of such equipment. Niro, for example, showed thes ingle fluid head used in their ceramic drying plants, while Krauss Maffei showed the spray head of their recently introduced drier for pastes and sludges. Atomising in this design is obtained through an annular compressed-air nozzle which directs the air against a fine curtain of sludge produced by forcing the material by means of a screw feeder through an annular orifice concentric with the air nozzle.

Another specialist in this field, Büttner, had on view a small drier, representative of their range of spray driers which can be equipped with various atomising devices depending upon the kind of product required. For example, two-fluid atomising is sometimes used if a finely divided product is required, whereas single-fluid atomising will often give a coarse product. If the product is to be as coarse grained as possible, then a mixed feed of air and fluid is passed through the spray nozzles. In addition, Büttner provides rotating disc atomisers. Ranges of the driers cover water evaporation rates of 60-4200 lb/hr for drying gas inlet temperatures of 260-300°F, and installed power varies from 7-280 hp.

A small drier with two-fluid atomiser for research purposes was one of the exhibits of the VEB Molekularzerstäubung, Meissen. This drier has an evaporative capacity of 2-3 kg/hr of water with an air feed at 160°C. From display and other material presented by this company it was apparent that they make a range of similar driers. These have, for drying gases at 160°C, water evaporation rates of from 2-2000 kg/hr. In some applications (Fig. 3) the units may be used as spray crystallisers, in which case the air heater is replaced by a chilled, extended surface cooler.

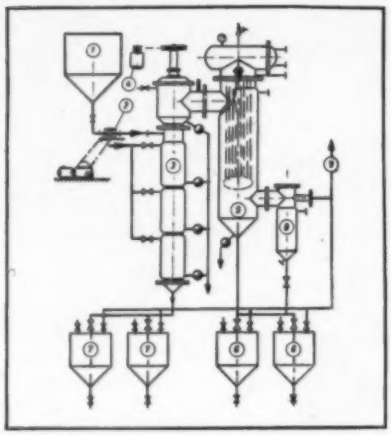

Fig. 2. Sambay evaporating plant. (1) Feed tank. (2) Metering pump. (3) Wiped film evaporator. (5) Evaporative condenser. (6) and (7) Receivers. (8) Cooled trap. (9) Vacuum connection.

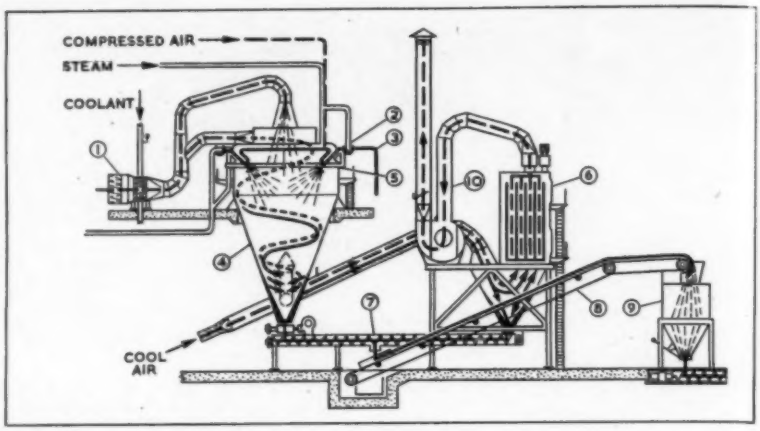

Fig. 3. Spray crystalliser plant offered by VEB Molekular Zerstaübaung. Meissen. (1) Air cooler. (2) Heated manifold for solution. (3) Product feed. (4) Drier. (5) Twin fluid spray nozzles. (6) Bag filter. (7) Screw conveyor. (8) Belt conveyor. (9) Crystal receiver. (10) Induced-draught fan.

Ring Driers

Of ring driers, that shown in diagram form by Krauss Maffei is worthy of mention. This is used for difficult-to-dry filter cakes, and in it the cake discharged from a rotary vacuum filter is fed via a screw conveyor-mixer to an air-swept hammer mill. The product is then conveyed by the warm air passing through the mill to the ring ducting, from whence it passes into a centrifugal separator which returns oversize material into the hot air stream fed to the mill. The finer and now dried product is fed to twin cyclones, one of which discharges dry material back into the screw mixer where it is incorporated with the fresh, wet, filter-cake feed. As a result, the material fed to the mill is dry enough to avoid adhesion to the walls of the apparatus. The arrangement is a flexible one, since it allows the requisite fineness for rapid drying to be achieved by the hammer mill, and because the moisture of the mill feed is readily controllable. In one arrangement of this drier the partially dust-free air is led into a wet separator from where the recovered dust plus water is recirculated back to the rotary filters.

As a rule these driers are tailor-made for a particular duty and product; an idea of the sizes can be gleaned from the fact that in one recent unit the cross-section of the ring section measured 0.65 × 1.3 m.

Another firm to show a ring drier was VEB Molekularzerstäubung. Meissen, whose spray drier adapted as a crystalliser has been previously described. This drier has a separator fitted in its circuit upstream of the cyclone which receives the main products, and the oversize from this separator is returned back to the feed via a screw. It is possible for this layout to be modified by the inclusion of a valve at the cyclone base which diverts a proportion of the dried product back into the feed.

Evaporators

Two firms, Luwa A.G., of Zürich, and Samesreuther (Butzbach/Hessen), displayed wiped film evaporators each bearing a close resemblance to the other and of similar sizes.

A difference appeared to be, however, in the actual arrangement of blades, for in the case of the Sambay machines (made by Samesreuther) the blading consists of vertical strips fitted peripherally around a series of circular rings attached to the centrally rotating shaft, whereas the Luwa machines are fitted with vertical radial blades. Other differences would seem to be in the length of evaporator body in the case of the largest model from each firm; the Luwa has a heated length of 4.2 m, whereas the Sambay has a length of 4.7 m; as a result, the heating surface in the latter case is 8.8 m^2 compared with the Luwa's 7.9 m^2 Output of the largest Sambay model is approximately 600 kg/h of distillate based upon water. Evaporators of this kind are widely used where high-melting point organic substances have to be distilled under vacuo in order to avoid decomposition (Fig. 2), and for end products of high viscosity.

In addition to these evaporators, multiple-effect forced-feed and natural circulation types and evaporators with or without vapour recompression were shown by a few firms, including Wilhelm Wiegand Maschinenfabrik, Merseburg.

Distillation Equipment

Apart from the columns in glass and porcelain referred to in Part I of this article (see also Fig. 4), there was surprising scarcity of distillation equipment and no fundamentally new designs were presented. However, the French concern, Compagnie des Ateliers de la Loire, Paris, showed a type of mass transfer device of fairly recent origin which uses the jet transfer principle. The hydraulics are so devised that the liquid on a particular tray is entrained by a jet of vapour in which the major proportion of mass transfer occurs. The entrained liquid separates from the vapour by impact upon the walls of the column, it then falls downwards to the next plate where the jet entrainment-mass transfer action is again repeated (Fig. 5).

Blowers and Compressors

As is usual with exhibitions which set out to display a comprehensive range of processing equipment, machines for supplying energy to fluids for transportation purposes were in abundance. The largest of these was an axial flow fan shown by the East German firm VEB Maschinenfabrik NEMA capable of a throughput of $1\frac{1}{2}$ 10^6 cu. m/hr (Fig. 1).

Of higher pressure machines, the combined multistage centrifugal blower and expansion turbine shown by Gutehöffnungshütte (West Germany) proved one of the most interesting of its kind on view. This machine has been designed for pressure nitric acid plants and is constructed from stainless steel; it has five radial stages, for compressing the nitrous gases to the absorption pressure, plus a single turbine expansion stage, mounted upon a common shaft, through which the exhaust gases from the absorption system

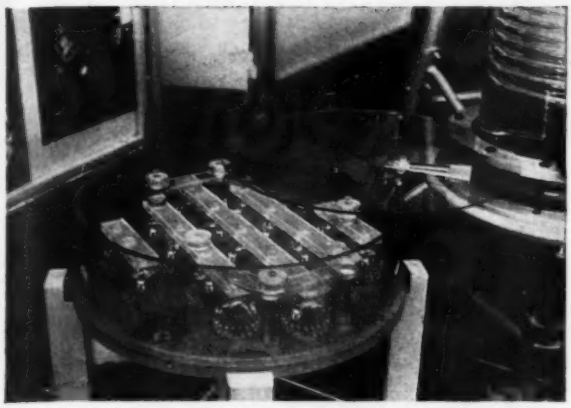

Fig. 4. Glass distillation bubble-cap plate shown by Jena Glassworks. The assembly is held together by glass nuts and bolts (right foreground).

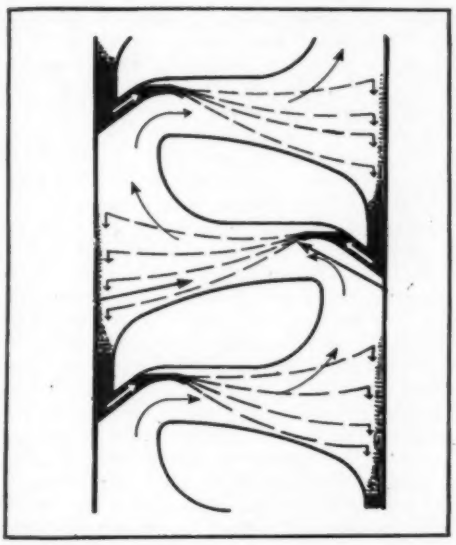

Fig. 5. Example of French distillation equipment. The jet transfer plate shown in operation in a 4-in. column.

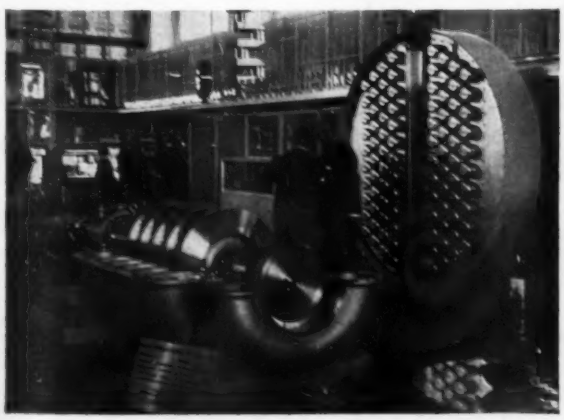

Fig. 6. Stainless-steel five-stage centrifugal compressor shown by Gutehoffnungshütte Sterkrade AG.

are expanded. The difference between required and recovered power is supplied by means of an electric motor connected to the free end of the shaft via an epicyclic gear. The advantages of this combination are oil-free compression, simple and cheap maintenance, and reduced bearing losses through the mounting of compressor and expander upon a common shaft. The performance figures for the compressor section are as follows:

Nitrous gas throughput	20,600 cu. m/hr
Compression ratio	2.7 approx.
Operating temperature	55°C
Power required	1290 kW
RPM	6140

And for the expander the relevant data are:

Quantity of gases	16,000 Nm^3/h
Inlet pressure 2.8; outlet pressure, 1.1 atm.	
Temperature of inlet gases ...	170°C
Power recovery	420 kW

Another machine shown by the same company was a twin intermeshing screw compressor, again offering a completely oil-free compressed gas. Major advantages of this compressor are its compactness and its ability to work as a vacuum pump. As a compressor it is available in one to three stages with final pressures of 4 to 16 atm respectively, while as a vacuum pump (single stage) it will give a pressure at suction of 0.1 atm. The outputs are in the range 500-23,000 cu. m/hr. The pressure developed is almost independent of the speed of rotation, and the adiabatic efficiency is approximately 70%.

A new centrifugal compressor of sound conventional design was shown also by VEB Pump and Blower Works of Leipzig. This is a six-stager (type 6 VRZ 2/300/225) with a throughput of 40,000 s m^3/h and a delivery pressure of 9 atm. The first stage is arranged for double flow and has intercooling after the first, third and fifth stages; isothermal efficiency is 60% and the pulsation limit is 65% of the average throughput.

Apparatus for Mechanical Separations

An interesting feature of a suspended sugar type centrifugal shown by VEB Maschinenfabrik Sangerhausen was the arrangement for programme control of its operation. The machine has automatic discharge, charging, and washing mechanisms which are operated in the desired sequence by an electronic programme-controller, the duration of each operation being variable at will. Drive is by synchronous motor fitted with generator braking.

Another new centrifuge was demonstrated by VEB Erste Maschinenfabrik Karl-Marx Stadt, this being a twin pusher-type machine with a basket diameter of 0.45 m. The hydraulic control permits the available capacity to be fully used through the facility of pusher stroke adjustment which can be performed while the centrifuge is running.

Another advantage of this design is that it avoids the difficulty which sometimes occurs with single pusher centrifuges, namely, the entry of solids behind the pusher disc; the design provides a double path for the discharge of solids. Output is in the range 2800-3000 kg/hr.

Decanting Centrifuges

Included among the impressive Krauss-Maffei-Imperial machinery were several types of centrifuge, one a pusher type suitable for easily filterable crystalline products, and particularly useful when used in combination with a drier system. The peeler centrifuge, shown as a pressure-tight machine, can be operated at pressures up to 5 atm, while the remaining centrifuge to be seen was a new, horizontal, continuous decanter type. In this new model (type KVZ) the solids are discharged from the conical rotor at the narrower end by means of a worm, while the liquid leaves at the wider

end through an adjustable draw-off tube. The machine can offer its product in various states of dryness and it can function as a classifier. Thus by means of a change in the speed of the rotor—readily carried out by changing the ratio of the belt drive—the amount of moisture retained can be varied. Again by changing the speed of the worm discharge (by means of a variator) the time to pass through can be changed—another adjustment affecting the moisture final content. Further, the liquid level and, hence, the residual wetness can be determined by adjusting the draw-off tube while the centrifuge is running. Finally, adjusting the inlet tube position and thereby altering the extent of the feed zone affords another means of varying the time the material takes to pass along the drum. Two sizes are made, one with a bowl of 0.42-0.22 m and the other with bowl dimensions of 0.75-0.42 m in diameter.

Centrifugals were well represented by a number of other firms, such as Westfalia and Carl Padberg. Foremost among the models shown by the first-named company was a pressure-operated machine (capacity 20,000 l/hr) for separating sludges. The Carl Padberg machines included tubular centrifuges capable of producing a centrifugal effect 50,000 × gravity and which with some models can be operated under a pressure of 2 atm. Different types of tube according to the duty required can be fitted.

Filter Presses and Vacuum Filters

The filter press field was another where East German equipment was predominant. VEB Maschinenfabrik Halle, a case in point, displayed a variety of chamber and plate-frame processes. Features of note are heating and cooling arrangements, high working pressures up to 35 atm and hydraulic closing device which applies a pressure of 300 atm on the press cylinder. The largest plate sizes are 1 m² and filtering surfaces of 170 m² can be provided in a press.

Of the several makes of rotary vacuum filter to be seen at the Fair, the new rotating pan filters shown by VEB Schwermaschinenbau "Karl Leibknacht", Magdeburg, were especially interesting. The approximate capacity offered by this design per sq. ft of filter service for granular crystalline products varies from 210-2500 lb/hr with a residual moisture of 5-20%; four sizes of filter are available with a range of filtering areas of 5.5-130 sq. ft. Among other types of rotary vacuum filter shown by this company were some for the paper industry employing Stridlund-type drums giving a surface of 220 sq. ft; and internal rotary filters for slurries containing solids of high specific gravity. These filters have a maximum filtering surface of 270 sq. ft.

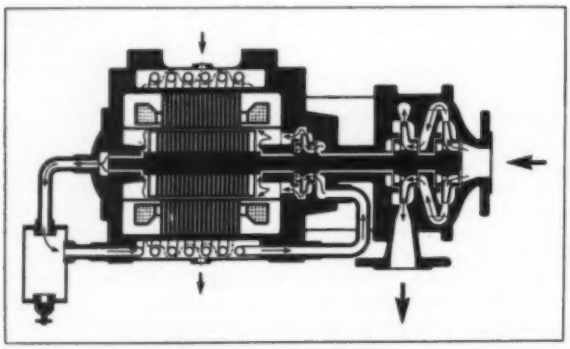

Fig. 7. A two-stage stuffing-box-less pump manufactured by Ladendorf. This company showed a number of variations of this pump.

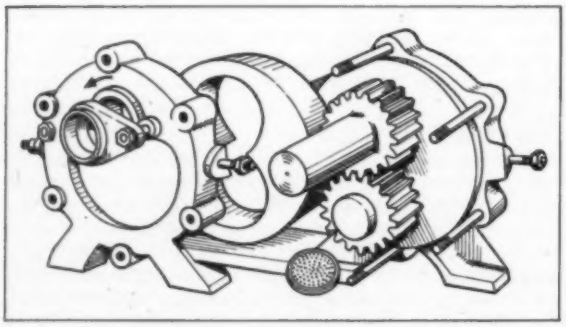

Fig. 8. Ceramic tooth wheel pump shown by VEB Keramic Works, Hermsdorf.

Particle Size Reduction Machinery

Particle size reduction machinery, a field in which German technology has long excelled, was represented by firms from East and West Germany. VEB Hartzkleinerungsmaschinen, Teltow, for example, had on view a new air-swept enclosed runner mill (type H/LM for medium and large output) of exceptionally robust construction; VEB Schwermaschinenbau "Ernst Thälmann", Magdeburg-Buckau, displayed an example of their swing jaw crushers which have a feed opening of 1.8 × 1.4 m, and a jaw setting of 0.3 m; these mills can crush hard feed at the rate of 300-350 cu. m/hr. Shocks produced by the crushing action are in the main reduced by a heavy flywheel and a further point in the design is the ease of replacing the swing jaw. Another maker of heavy grinding machinery, VEB Zementanlagenbau, Dessau, a firm specialising in complete cement plants, also showed a number of crushing machines; in particular its double- and four-roll crushers. These machines, whose field is the reduction of material received from primary reducers such as the jaw crusher, or the primary reduction of products prone to caking, will crush 80-mm lumps for outputs of 8-60 tph in the case of the two-roll machines, and from 13-30 tph for the four-roll machines. Crushing rolls with various teething can be supplied according to the duty required. The primary jaw crushers made by this company will accept feed of 120 × 60 mm up to 1 × 0.6 m for outputs ranging from 0.1-180 cu. m/hr. The largest high-speed hammer mill manufactured by this company has a rotor diameter of approximately 1 m, is driven at 730 rpm by a 250-kW motor and has an output up to 160 cu. m/hr.

Among the exhibits of the Brabender-Technologie, Duisburg, was a newly developed mill (the Ultra-Rotor) in which the major mechanism of particle size reduction takes place by impact in the air stream, with only a small proportion of reduction being carried out by the machine itself. The machine is suitable for the fine grinding of plastic and other materials difficult to handle in impact mills.

Separators for Grinding Plant

The same firm also presented a newly developed separator (the Micro classifier, type B) which consists of a group of small vertical cyclones connected in series, the particle separation being obtained by varying the amount of air passing through, an apparatus intended mainly for use as a separator for the material ground in the Ultra-Rotor.

Another development in particle separation machinery was shown by Alpine-AG, Maschinenfabrik und Eisengieberei, Augsburg, this being an improved version of an earlier classifier. The improved design can take a solid load of 8000 kg/hr with a separating range of 10-100 microns.

Centrifugal classifiers were shown also by VEB Zementlagenbau, these being twin-cone machines of sound conventional design in which the rotating plate is direct coupled to the prime mover: two varieties are available, one for fine

Fig. 9. Wire-wound pressure vessel produced by VEB Maschinenfabrik Germania.

(micron) size and the other for coarse separations. The output range of the former is 0.3-45 tph for power consumptions of 0.9-37 kW. The coarse separation equipment is offered with outputs of 8-150 tph for power requirements of 3-32.5 kW; with these models the rotating plate is driven through a gear unit to give speeds in the range 520-220 rpm.

One of the few colloid mills at the Fair came from the Swiss firm of Fryma-Rheinefelden, a machine of the high-speed disc type capable of producing micron-size particles. A variation of this mill equipped with corundum discs can be supplied for operating under a pressure of 10-12 atm; outputs vary from 30-1000 kg/hr with motor hp of 3-20.

Instruments

A considerate amount of space was devoted to automatic process control equipment, most of it being occupied by German firms, East and West. VEB Messgeraete und Armaturenwerk "Karl Marx" (Magdeburg) showed a wide selection of new instruments with tri-mode functions for controlling the commonly encountered variables in chemical processing. VEB Geraete und Regler-Werke, Teltow, also had many new products to offer, including, in the field of pneumatic control equipment, differential pressure transmitters for differential pressures between 100 mm and 10,000 mm head of water, suitable for working pressures from 1-250 psi. Another range of transmitters is for differential pressures up to 560 psi at operating pressures of 2240 psi. In addition to a number of temperature controllers, moving coil transmitters, pneumatic servomotors and position indicators, the Teltow firm demonstrated two new control devices for use with jet pipe control systems—the one a hydraulic follow-up control piston and the other an electrohydraulic remote-control piston. The former is used for furnace pressures regulation, and the latter finds application in the remote control of hydraulic servomotors.

Instructional aid instruments shown by this firm included one designated "Computer Arrangements". This aid can demonstrate the essential functions of a control system; circuit arrangements provide for addition and subtraction, multiplication and division, raising or lowering to a power, and differentiation or integration. By means of it, time lags can be studied.

Among analytical instruments shown by Willy Giede of Berlin (Oberschoeneweide) were magnetic oxygen recorders, gas chromatographs, and CO + H_2, CO_2 and SO_2 meters.

Ludwig Seibold, Vienna, showed a number of industrial *p*H instruments of unusually robust appearance. One group of instruments combined the direct reading instrument and the electrode system in a single tubular housing, thereby providing a convenient instrument for intermittent measurement. Glass or antimony electrode systems are employed the ranges being 2-12 *p*H with an accuracy of ± 0.1 *p*H. Instruments and controllers for permanent installation were similarly serviceable in appearance, a commendable feature of the recorders is their suitability for multi-electrode installations; the maximum number of electrodes which can be connected to a single indicator recorder is at present 6. The closed-loop *p*H control consists of an electronic amplifier with *p*H indication and automatic temperature regulation, plus electro-pneumatic controller possessing the usual control actions for operating a diaphragm-motor valve.

Apart from the trend towards electric systems, a feature of most East German control and measuring instruments, is their conformity to the Uniform International Construction Box System in Control Engineering, a system which permits a high degree of interchangeability and the easy assembly of a control system.

Pumps for Chemicals

That a wide range of liquid pumps was to be seen was not surprising in view of the high reputation of German manufacturers in this field, and glandless pumps in particular were strongly represented. For example, VEB Pumpenfabrik Oschersleben showed one of a range of single-stage canned rotor centrifugal pumps, the deliveries varying from 2-70 cu. m/hr from heads in the range 10-60 m.

Amag-Hilpert Pegnitz Huette A.G., Nürnberg, was another company to display glandless pumps. Worthy of mention is this company's type CN single-stage pump, which has an excellent characteristic; maximum head developed is close to 100 m and outputs (at a much lower head) approach 250 m^3/hr. Another vertical pump by the same company is the type LUV, which also operates vertically, but has its pump portion fitted above the motor. This component is fitted within a specially cooled compartment for separating the motor from the pumped liquid and through which circulates a fluid under pressure, this being cooled by a water-cooled heat exchanger installed in the circuit.

In the sphere of high-pressure piston pumps mention must be made of the series shown by VEB Pumpenwerke Salzwedel. Two designs are offered, one with the outputs which vary from 2 l/hr for a 400-atm discharge pressure, up to 315 l/hr when the pressure is 1 atm; the other has an output of 15 l/hr at 640 atm, up to 600 l/hr at 10 atm.

Plastic Pumps

Cast epoxy, single-stage centrifugals, suitable for pumping hydrochloric acid solutions, 10-50% H_2SO_4, nitric acid up to 20% as well as alkaline solutions were one of the major exhibits of VEB Pumpenwerk Erfurt, the range providing heads up to 75 m for deliveries from 2-85 cu. m/hr. These pumps, somewhat bulky in appearance, employ closed impellers and the maximum normal working temperature is 80°C. The same company, who manufacture also process pumps in stainless steels, are expecting a rapid extension in plastic pump applications, because the latter are cheaper and also because their reduced weight makes installation and maintenance easier. The same company demonstrated this trend further with a group of cast epoxy peripheral pumps with outputs of 4-25 cu m/hr for heads of from 28-32 m.

Suitable for self-lubricating liquids, the self-priming gear pump displayed by VEB Keramische Werke, Hermsdorf (Fig. 8), will tolerate sudden temperature differences of up to 50°C and temperatures up to 120°C.Outputs from the two models at present available vary from 0.25-144 cu m/hr and heads of 10-40 m depending upon the fluid viscosity can be obtained, and a speed variation is available Mechanical features include an easily withdrawable sleeve coupling for immobilising the pump.

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THE PURIFICATION OF INERT GASES BY HOT URANIUM—PART II

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The first part of this article has described the experimental technique and the results obtained, together with the elementary theory associated with the passage of a low partial pressure of reactive gas over a hot metal. Part II shows how the theory and experimental results may be applied to gas purification in simple cases, and discusses the reactions involved, particularly uranium-carbon monoxide, with brief reference to other hot metal systems.

4.1 Application of Results to the Design of Purifier Systems

THE tables below present the volume of free space, V ml, of a uranium bed required to attain the purification factors given at the appropriate temperature. The values have been calculated for the following conditions applicable to all tables.

(a) A flowrate, F_0, measured at room temperature, of 500 ml/min. (≡0.0083 litre/sec. or 2.66 cm/sec. in a 1-cm radius tube).

The actual flowrate in a hot bed is $500 \times \frac{T°K}{293}$ ml/min., where T°K is the temperature of the bed in degrees Kelvin.

(b) A surface area of uranium turnings, δ, of 43.4 cm²/gm. This represents the specific surface area of turnings of dimensions $\frac{1}{8}$ in. × $\frac{1}{2}$ in. × 0.0025 in. (approx.) thickness, which are a convenient size in use. V has been calculated for a packing density, d, of 1 gm/ml by using $s = 43.4\ \text{cm}^{-1}$ in the rate equation.

From V, the geometrical volume V', of the bed for the above value of d is $\frac{V.19.7}{18.7}$, and the mass of uranium is V.

For other values of s, V should be multiplied by $\frac{43.4}{s}$.

For other packing densities, then $V' = V\left(1 + \frac{d}{18.7}\right)$, and the mass of uranium is $V \times d$ g.

k_s has been shown to vary with time of reaction, but the values used in compiling the tables are average values and applicable over the whole of the lifetime of the bed. A variation in k_s outside ±25% would not be expected under normal operating conditions over the above time.

The following table may be used for carbon monoxide concentrations from about 200 to 10,000 vpm. k_s increases at lower concentrations (Table I) and the figures could safely be halved if it is known that the gas to be cleaned up contains less than 200 vpm of carbon monoxide.

Up to 700°C, 50% of the initial charge of uranium reacts with carbon monoxide, and 1 mol. U is equivalent to 1.01 mol. CO. Determinations of the lifetime of the uranium bed in a particular duty should take these factors into account. Above 700°C, the life of the bed is limited and much less than 50% of the uranium is effective.

TABLE X—Size of Uranium Bed Required for Carbon Monoxide Removal from Argon

Temperature (°C)	550	575	600	625	650	675	725	850
k_s	0.0025	0.010	0.028	0.075	0.127	0.162	0.103	0.063
p_0/p_1	volume of free space, V (ml)							
2	235	39	14.2	5.4	3.3	2.7	4.4	8.1
5	550	90	33.0	12.5	7.7	6.2	10.0	18.8
10	785	130	47.0	18.0	11.0	8.8	14.6	27.0
20	1,020	165	61.5	23.5	14.3	11.5	19.0	35.0
50	1,335	220	80.0	30.5	18.4	15.0	25.0	45.0
100	1,570	255	94.0	36.0	22.0	18.0	29.0	53.5
200	1,800	295	108	41.5	25.0	20.5	33.5	62.0
500	2,120	345	127	49.0	29.5	24.0	39.5	72.5
1,000	—	385	141	54.0	33.0	26.5	44.0	80.5
2,000	—	425	155	59.6	36.0	29.0	48.5	88.5
5,000	—	475	175	67.0	40.5	32.5	54.0	99.5
10,000	—	510	190	72.5	44.0	35.5	58.5	107

TABLE XI—Size of Uranium Bed Required for Carbon Dioxide Removal from Argon

Temperature (°C)	250	350	450	550	650	750
$k's$	0.875	1.14	1.48	2.49	3.47	4.40
$\sqrt{p_0}-\sqrt{p_1}$	volume of free space, V (ml)					
1	0.78	0.71	0.64	0.43	0.35	0.31
1.5	1.17	1.07	0.95	0.65	0.52	0.48
2	1.57	1.42	1.27	0.87	0.70	0.61
3	2.35	2.13	1.91	1.30	1.05	0.91
4	3.10	2.84	2.54	1.73	1.39	1.22
6	4.7	4.26	3.82	2.60	2.09	1.85
8	6.3	5.7	5.1	3.47	2.79	2.44
12	9.4	8.5	7.6	5.19	4.2	3.66
16	12.5	11.4	10.2	6.9	5.6	4.9
24	18.8	17.0	15.3	10.4	8.4	7.3
32	25.0	22.5	20.5	13.9	11.2	9.8
48	37.5	34.0	30.5	21.0	16.7	14.6
64	50.0	45.5	40.5	27.5	22.3	19.5
86	67.5	61.0	54.5	37.5	30.0	26.2
100	78.5	71.0	63.0	43.5	34.7	30.5

To use the above table, the initial gas concentration, p_0, must be known. For example, if $p_0 = 1000$ and a purification factor of 100 is required, then $\sqrt{p_0} - \sqrt{p_1} = 10\sqrt{10} - \sqrt{10}$, or 28.5, whence $V = 20$ ml approx. at 350°C. 100% of the initial uranium charge is effective and 1 mol. U is equivalent to 2 mol. CO_2.

A bed size based upon these figures will reduce the carbon

dioxide concentration to the desired level, but since reaction yields carbon monoxide, the outlet gas will be contaminated unless the size of the bed is adjusted in accordance with the figures in Table X. Where the presence of carbon monoxide can be tolerated in the outlet gas, then Table XI may be used. At 500°C and below, <1% of the reaction product, carbon monoxide, will be removed from the gas stream by the above bed volume.

TABLE XII—Size of Uranium Bed Required for Oxygen Removal from Argon

Temperature (°C)	250	350	450	550	650
k_δ	0.05	0.13	0.245	0.34	0.425
p_0/p_1	volume of free space, V (ml)				
2	4.8	2.2	1.3	0.93	0.99
5	11.0	5.1	3.1	2.2	2.3
10	15.8	7.2	4.4	3.1	3.3
20	20.5	9.4	5.8	4.0	4.7
50	27.0	12.5	7.7	5.3	5.6
100	31.5	14.5	8.9	6.2	6.6
200	36.5	16.5	10.2	7.1	7.5
500	42.5	19.5	12.0	8.4	8.8
1,000	47.5	21.5	13.4	9.3	9.8
2,000	52.0	24.0	14.7	10.2	10.8
5,000	58.5	26.5	16.5	11.5	12.1
10,000	63.0	29.0	17.8	12.4	13.1

85% of the initial uranium charge is effective and 1 mol. U is equivalent to 1 mol. O_2.

Packing Density and Pressure Drop

A packing density of 1.0 gm/ml is the average obtained by loosely packing turnings, $\frac{1}{2}$ in. × $\frac{1}{2}$ in. and δ = 43.4 sq. cm/g. into a cylindrical tube. Light tamping will increase d to about 2 g./ml, but the use of packing densities higher than about 2.5 g./ml is not recommended on account of the increased pressure difference across the bed (Figs. 6 and 7—see Part I).

Lower or higher values of δ will decrease or increase respectively the average value of the loose packing density, d. In these cases, either a higher or lower pressure of packing should be used to bring d close to a value of 1.0, or, alternatively, the volume of the bed should be recalculated at the new packing density. The former method has limits, since compression to obtain higher packing densities will result in higher pressure differences, and there is an obvious limit to more widely spacing the turnings.

In the design of any uranium bed close attention should be paid to the pressure drop expected. The results in Figs. 6 and 7 may be used only as a guide, since they are applicable only to beds packed with turnings where δ = 43.4 sq. cm/g. For tubes of radii other than 1 cm, the pressure difference should be multiplied by the factor $\frac{r^2}{1^2}$, where r is the radius of the tube to be packed. The values should also be increased by the factor $(\mu_{T°C}/\mu_{20°C})(F_T/F_O)$ where $\mu_{T°C}$ and $\mu_{20°C}$ are the viscosities of the carrier gas at T°C and 20°C respectively.

Compatibility

A working temperature of 550°C has been quoted[9] as safe for mild and stainless steels. Uranium and iron or nickel form eutectics at 725°C and 740°C respectively,[10, 11] although combination is unlikely under the conditions encountered in a gas purifier, where the uranium is always covered with a surface film of product. Penetration rates of 0.020 in./min. at 850-900°C of stainless steel by uranium have been observed.[12]

Above 550°C, ceramic liners of mullite or alumina are necessary, although possible alternative liner materials are tantalum, niobium or graphite. Silica has been used successfully in laboratory purifiers below 800°C, but is not recommended for long-term use.

Treatment of Uranium and Configuration of Bed

Uranium turnings are recommended for use in purifiers, since they allow a considerable variation in packing density to be used. They are usually manufactured and transported under oil and two washings with trichloroethylene followed by one with petroleum ether and drying without application of heat are necessary before use. If the turnings are heavily contaminated with oxide, then dilute hydrochloric acid treatment should be used to remove this. The uranium bed should not be brought to full working temperature unless the total concentration of impurity is less than about 6000 vpm. High concentrations (>10,000 vpm) or temperatures in excess of 700°C result in partial deactivation of the metal.

Where possible, uranium beds should be in a vertical position so that when a partial collapse occurs (Fig. 1, Part I) the gas must still pass through the metal and channelling is avoided. The bed should be divided into sections by horizontal plates: this minimises the risk of choking the bed with finely divided reaction product.

Dust Carry-over

Quantities of dust carried in a gas stream may be calculated from the results in Table III by application of the equation

$$V = \frac{x^2 g}{18}(\rho_\delta - \rho)$$

where V is the terminal settling velocity, μ the viscosity of the carrier gas, x the diameter of the particle, and ρ_δ and ρ the respective densities of particle and carrier gas. Results so obtained, however, are greater than those experimentally determined, since the results in Table III represent two of the extreme cases of excessive dust formation from high impurity concentration (>500 vpm) and bed operation to near exhaustion point.

Dust formation is not excessive, although it is composed of particles of less than about 4 μ which are difficult to filter. The dust particles may be pyrophoric, especially if the operating temperature has been less than 500°C, when hydride may be formed.

Example of Design of Uranium Bed

Suppose that the gas to be purified contains 1000 vpm carbon monoxide which is required to be reduced to 10 vpm i.e., $p_0/p_1 = 100$. Design problems limit the temperature to 600°C. Reference to Table X gives

$$V = 94 \text{ ml}$$

$$\text{whence } V' = \frac{94 \times 20.7}{18.7} \text{ ml}$$

for a packing density, d, of 2.0 g./ml δ for the turnings is 37.8 sq. cm/g.

$$\therefore V' = \frac{94 \times 20.7}{18.7} \times \frac{43.4}{37.8}$$

so that the geometrical volume, V', is 119 ml and the mass of uranium required is 188 g.

Since approximately 1.0 mol. U ≡ 1.0 mol. CO, and only 50% of the uranium may be effectively used in carbon monoxide removal, then the weight of the latter to be reacted with 188 g. is

$$188 \times \frac{50}{100} \times \frac{28}{238} \text{ g.}$$

and the volume

$$188 \times \frac{50}{100} \times \frac{28}{238} \times \frac{22.4}{28} \text{ l.}$$
$$= 8.85 \text{ l. at NTP.}$$

which is equivalent to 8.85×10^3 litres of inert gas at NTP containing 1000 vpm carbon monoxide. The lifetime of the

bed is $\frac{8.85 \times 10^3}{0.5}$ min. or 295 hr.

Distinction has to be made at this point between "one-pass" systems and circulating systems.

(i) "One-pass" Systems

Suppose that the total volume of gas to be cleaned up is 5×10^6 litres at atmospheric pressure, then the total weight of uranium required is

$$\frac{188 \times 5 \times 10^6}{8.85 \times 10^3} \text{ g.} = 106.0 \text{ kg}$$

and in order to retain the same purification factor of 100, F_0 must be increased by the same factor, i.e., from 500 ml/min. to

$$\frac{500 \times 5 \times 10^6}{8.85 \times 10^3} = 283 \times 10^3 \text{ ml/min.}$$

The geometrical volume of the bed is 59.0 l., and, assuming a single cylindrical bed with $h = 1$ m.,

then $\pi r^2 . 100 = 59.0 \times 100$

where r = radius of bed in cm.

$$r^2 = \frac{590}{\pi} \text{ and } r = 13.7 \text{ cm.}$$

Alternatively, the bed may be divided into a number of smaller beds, in series or in parallel, whose overall performance is identical with a single bed.

Reference to Figs. 6 and 7 gives a pressure difference of 0.15 cm Hg for $d = 2.0$ g./ml, $F_0 = 2000$ ml/min., $T = 20°C$, $l = 10$ cm, $r = 1.0$ cm. In the above case, the pressure drop over the bed is

$$0.15 \times \frac{283 \times 10^3}{2000} \times \frac{100}{10} \times \frac{1^2}{13.70^2} \times \frac{873}{293} \times \frac{\mu 600°C}{\mu 20°C}$$

$$= 3.37 \times \frac{\mu 600°C}{\mu 20°C}$$

For argon carrier gas, $\frac{\mu 600°C}{\mu 20°C} = 2.28$ and pressure drop = 7.67 cm. Hg, which is a relatively large pressure drop. This can be reduced by lowering the packing density, decreasing, the length to diameter ratio, or decreasing the flowrate.

(ii) Circulating System

Assuming a leak-tight system, then the mass of uranium required may be found if the quantity of impurity to be removed is known. Suppose this is 1.2×10^4 l., then the mass of uranium required, still at 600°C,

$$188 \times \frac{1.2 \times 10^4}{8.85 \times 10^3} = 255 \text{ g.}$$

Increasing the flowrate in the same proportion gives $500 \times \frac{255}{188}$ cu. cm/min. = 677 cu. cm/min.

This combination of results is still based on $p_0/p_1 = 100$, which, with knowledge of the volume of the circulating system to be cleaned up, enables the time of clean-up to be found.

When known leaks are present, or when manipulation of the system admits known quantities of impurity, then an additional quantity of uranium is necessary.

4.2 Comparison with Zirconium-titanium Alloy and other Hot Metal Systems

Magnesium and calcium have been widely used[6] to remove oxygen and nitrogen from argon, but no details of the efficiencies of these metals for carbon monoxide, carbon dioxide and water removal are available. The use of these metals has a number of disadvantages additional to the use of hot metals generally; namely, rapid retardation by reaction products, volatilisation giving pyrophoric metal dust and the close proximity of the operational temperature to the melting point of the metals. Sodium/potassium alloy, magnesium/calcium alloy and barium have been used similarly but are efficient only in liquid form.

High temperatures are necessary for the purification of gases using zirconium and titanium. Table XIII compares the behaviour towards carbon monoxide of 50 atomic per cent zirconium/titanium alloy with uranium. The increased reactivity of the alloy with carbon monoxide at high temperatures (>800°C) is probably due to diffusion of oxygen into the lattice leaving the surface relatively clean, although the latter continues to deactivate with the build-up of ZrC and TiC, since carbon does not rapidly diffuse into the metal.[13]

The principal disadvantages of the use of hot uranium and hot metal gettering methods generally are (a) fire hazard should accidental rupture of pipework occur, followed by air or water ingress; (b) compatibility and design problems for high-temperature operation; and (c) deactivation by excessive impurity or temperature.

TABLE XIII—Comparison of Uranium and Zirconium-titanium Alloy for Removal of Carbon Monoxide from Argon

Zirconium-titanium		Uranium
750	Temperatures at which reaction starts (°C)	550
900–950	Optimum working temperature (°C)	600–725
10–15	Efficiency (% metal used up to the point where 50% of CO is being removed)	30–50
First order	Kinetics	Near First order
0.50 at 978°C	k_S (for 1000 vpm CO)	0.164 at 675°C
ZrO_2, ZrC: no dust: residue very brittle	Product	UO_2, UC_2, C, partly as fine dust
About 11	Cost (unfabricated) (£/kg)	About 12
Will react rapidly with water and air when hot	Safety	Reacts vigorously with H_2O (low order explosion) and air

4.3 Uranium-carbon monoxide

It is of interest to compare the relative importance of the following three possible reactions between uranium and carbon monoxide.

$$U + 2CO \longrightarrow UO_2 + 2C \quad \ldots\ldots \text{(i)}$$

$$2U + 2CO \longrightarrow UO_2 + UC_2 \quad \ldots\ldots \text{(ii)}$$

$$3U + 2CO \longrightarrow UO_2 + 2UC \quad \ldots\ldots \text{(iii)}$$

When the reaction is carried out at 675°C, free carbon is present in the product in addition to that combined with the uranium as uranium carbides. The quantity of free carbon present varies with the conditions of the reaction; e.g., under high flow conditions much of the carbon is carried away and deposited on the filter, but the average figure indicates that 34% of the uranium reacts by equation (i) when (ii) is the other reaction, and 26% when (iii) is the other reaction. Of the two reactions (ii) and (iii), the latter, resulting in uranium monocarbide formation, is considered to occur, since generally higher carbides require much greater temperatures for their formation than those used in the present work.[14] Also, the mass balance of the analyses (Table IV) favour the presence of the monocarbide rather than the dicarbide.

The total free energy change for reaction (i) at 717°C has a large negative value which implies that the partial pressure of carbon monoxide in equilibrium with uranium, UO_2 and carbon at high temperatures is negligible. No free energy data for the uranium carbides above 25°C are available, but it is highly probable that the free energy changes for reactions (ii) and (iii) are also large and negative.

Since the uranium is always covered with a film of oxide, carbon formation might be considered as taking place by the reaction

$$2\,CO \xrightarrow{UO_2} CO_2 + C \qquad \ldots.(iv)$$

followed by further reaction with the uranium

$$CO_2 + \tfrac{1}{2}\,U \longrightarrow \tfrac{1}{2}\,UO_2 + CO \qquad \ldots.(v)$$

giving an overall reaction as (i) above. However, from the magnitude of carbon deposition by (iv) as reported by Roberts, Walter and Wheeler,[15] it would appear that the direct reaction (i) would predominate in the present work.

The actual composition of the product is dependent upon many factors, including the concentration of carbon monoxide in the gas stream, and the life of the bed, since uranium nitride and carbides are reactive materials and may further react with the gaseous impurity. The nitrogen impurity is constant at about 2000 vpm, and when the carbon monoxide concentration is low, the proportion of nitride in the product increases (Table IV). U_3O_8 has not been considered as a reaction product, since it is rapidly reduced to UO_2 at 675°C by carbon monoxide.

The reduction in reaction rate at temperatures in excess of 700°C may be attributed either to the formation of a more cohesive film of reaction product, although the temperatures concerned are well below those at which true sintering occurs, or to the decreased reactivity of the γ-phase of uranium metal, which is slowly formed above 760°C. However, the fact that the decreased reactivity varies with the initial concentration of carbon monoxide (Fig. 3, Part I) indicates that diffusion through the surface film controls the reaction rate rather than the reactivity of the underlying metal. Thicker deposits are more rapidly built up with higher gas concentrations within the time of an experimental observation, which accounts for the variations in the recorded results in Fig. 3. It has been reported by Huddle[16] and Hopkinson[8] that the rate of the uranium-steam reaction falls off at temperatures above 800°C, which is probably due to "sintering", or similar change, in the oxide film.

It is difficult to appreciate the reason for the shape of the curves in Fig. 5 (Part I), since if the extent of the usefulness of the uranium bed was dependent upon the gradual build-up of the surface film, the initial horizontal portion should not be shown. Again, when less than 50% of the impurity is being removed, the uranium is by no means completely expended (Section 3.1.3, Part I) in reaction with both carbon monoxide and nitrogen. It is probable that a combination of the above effects is operating, and the low purification factor observed after the rapid fall may be due to the reaction between uranium nitride and carbon monoxide.

It has been assumed that the first-order equation for a chemical reaction has been satisfied by the experimental results obtained. However, the straight line (Fig. 4B) does not pass through the origin on extrapolation implying that the purification factor is >1 for infinite flow, and that the results obey an equation of the form

$$\log_{10}\frac{p_o}{p_1} = \frac{k_{s,s}V}{2.303F_T} + k'$$

Alternatively, k_s may vary with F_T for higher values for the latter. Curve A (Fig. 4, Part I) appears to obey the above equation at low flowrates but not at high rates, the possible variation of k_s with F_T becoming apparent at lower flowrates in comparison with Fig. 4B (Part I). It is thus clear that the reaction kinetics obey the first-order equation only approximately, but this is sufficiently close for the purpose of the present work.

Uranium-carbon dioxide

The oxidation of uranium by pure carbon dioxide has been studied in some detail.[17] The reaction was found to be rapid yielding UO_2 and carbon, but some doubt existed as to the exact mechanism of the reaction. Of the two possible initial reactions

$$U + 2CO_2 \longrightarrow UO_2 + 2CO \qquad \ldots.(vi)$$

$$U + CO_2 \longrightarrow UO_2 + C \qquad \ldots.(vii)$$

it has been shown in the present work that (vi) is the more prominent. Carbon monoxide has been recognised as one of the products of the reaction in concentrations corresponding to the carbon dioxide inlet concentration. Also, no carbon is found in the product of reaction of pure carbon dioxide and uranium under conditions where any possible gaseous product, carbon monoxide, may be carried away before reaction with the uranium, nor below 550°C, where the uranium-carbon monoxide reaction is very slow. Reactions (vi) and (vii) are each equally possible from free energy considerations.

Uranium monocarbide is rapidly oxidised by carbon dioxide so that in an incompletely reacted uranium bed, uranium carbide formed by reaction with carbon monoxide will not be present at the inlet end. Katz and Rabinowitz[18] report the presence of carbides in the reaction product.

Uranium-water

It has not been possible to present design data for the removal of water vapour in the present work. Results obtained varied appreciably from one uranium bed to another owing to the operation of some unknown factor relating to the activity of the uranium surface to water vapour, and the results presented in Section 3.4 are a selection of the most consistent figures obtained. Many further results were obtained with purification factors considerably below those quoted.

The increase of purification factor with increase in flowrate suggests that the measured reaction rate is controlled by diffusion of water through the oxide film to the uranium metal surface against diffusion of hydrogen in the reverse direction. The adsorption of hydrogen on the surface of the oxide film may also serve to retard the reaction.

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Symposium on Automatic Control

The first Congress of the International Federation of Automatic Control has just concluded in Moscow. This event attracted world-wide attention and over one thousand scientists and engineers attended from 30 countries. The British delegation of 90, led by Mr. J. F. Coales, an authority in this field, was responsible for 28 papers out of a total of 285.

Among them was one of great interest to chemical engineers, given by H. H. Rosenbrock on the transient behaviour of multi-component distillation columns. Other papers included one by Mr. Coales and Mr. P. Y. Lawrence, which dealt with the optimisation of automatic control systems, and another by Mr. T. Campbell-Macdonald which described automatic control systems in sugar manufacture.

The English papers presented are to be re-presented in London on September 27 and 28.

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SECOND EUROPEAN SYMPOSIUM ON REACTION ENGINEERING

A summarised account of the 25th meeting of the European Federation of Chemical Engineering

THE 25th meeting of the European Federation of Chemical Engineering on April 26, 27 and 28, 1960, was the second European symposium dedicated to Chemical Reaction Engineering. As in 1957, Amsterdam was chosen as the conference meeting place. As the impact of the first symposium is clearly emphasised by frequent reference to it in the literature, the importance of these meetings need hardly be stressed. Moreover, comparison of the two symposia shows an increase in number of papers, as well as an increase in the proportion of contributions from industry. This shows that the usefulness of these meetings is well recognised by those concerned with the practical application of chemical reaction engineering.

Impressions of the Symposium

The subjects dealt with were classified by the symposium committee in groups: introductory papers; selectivity and optimisation; reactions involving gas and liquid; reactions involving two liquids; distribution of residence time; mathematical techniques and models, and contact between fluid and solid. Moreover, two last-minute Russian contributions were presented in an additional session.

The above classification is not the only one possible, as was indicated in the final discussions session by van Krevelen. He used his micro- and macro-kinetics concept—well established since the first symposium—to give an excellent general review of the proceedings. Additional to these, one might consider the origin of the authors of interest. Excluding the Russian contributions, the importance of which can only be properly estimated when copies of them become available, of the 28 papers presented, 15 came from industry and 13 were of university origin. This division does not run parallel to one between papers of direct industrial importance and papers of theoretical value. Of course, the opinion of the organising committee is important in a comparison of the two, but from the papers itself it is clear that other considerations play a role as well.

The relatively small number of British papers were of wide variety, coming from a university and various industries. The same can be said of the German contributions, while papers from France, Norway and the Netherlands came from universities and coal and oil research stations only. The sole Swiss contribution was of industrial origin. With regard to any relation between theory and university, and practice and industry, it was apparent that the German contributions were all founded on a sound knowledge of existing theory, while the industrial application of this knowledge is the direct aim. There is within this group no difference worth mentioning between university and industry. As an important part of the university's contributions is based on thesis work, this once again stresses the fact that in Germany universities and industry closely collaborate. In this way the Germans seems to have found the so dearly needed balance between theoretical knowledge and use of experiments, a balance that is seldom not realised, a point stressed by the meeting's acclamation when van Heerden drew attention to it.

The contributions of the other Western European countries were in the main of more fundamental than of practical importance. This seems to be due partly in some cases to an over-estimation of companies' secrets, the result being a more fundamental presentation.

Another possible explanation is that in these countries the relationship between university and industry is different, while the staffs of the research institutes of the larger companies seem to be working from an academic point of view with a specific process in mind, rather than working on that process with the aid of their university background. Of course, this situation is the more profitable one in the longer run as it doubtless stimulates greatly progress in theoretical knowledge, but on the other hand it must be admitted that technical progress in Germany today has been made possible through the practice of using chemical engineering knowledge in engineering design.

Still another factor may, however, be of influence. As in the case of the first congress on reaction engineering, no papers on scale-up were presented. This narrowed the field covered considerably, which is in a way advantageous, but gives those who are mainly concerned with design considerations less chance of presenting their results. As the 1957 congress was followed by the scaling-up symposium in London of that year, the two together give a more complete picture of scientific and industrial achievement up to that time.

Congress Organisation

A few remarks on the organisation of the congress are perhaps in order. In general, notwithstanding the crowded programme, all sessions proceeded according to a well-kept time schedule, for which the organising committee deserve full marks. Some of the audience may have felt the disadvantages of two parallel sessions, especially as a number of preprints were available at the beginning of the meeting only. This, too, may have affected the discussions, although in general the papers presented were discussed according to their level, despite the difficulties that must have been

caused by the use of three languages alternately, and sometimes even simultaneously.

Introductory Papers

The introductory papers by Rietema and by Küchler were not open for discussion, as their nature was obviously a general one. Nevertheless, Küchler's paper contains information not published before in examples sustaining its leading thought that micro- and macro-kinetics are of equal value for industrial-scale reactions. The influence of small amounts of additives to a NiO catalyst on the activation energy in the oxidation of CO, and the discrepancies found in literature between the work of different investigators, were used to stress the point that more knowledge of the micro-physics of the catalyst surface is still necessary before the empirical knowledge of solid catalysts can be replaced by theory. As an example of macro-kinetics, the optimum conditions for the reaction $A + B \rightleftharpoons C + D$ are theoretically derived for chosen values of equilibrium constant, heat of reaction and temperature dependence. The behaviour of adiabatic and isothermic reactors is evaluated, as well as the influence of the number of reactors on maximum production of C and D.

Rietema's conclusions from an analysis of the "task for chemical reactor engineering" rather along established lines are that even in the very first stages of research on a new process chemical engineering knowledge should play a role, and that the whole process development is best covered by a single group of people going through all the different stages together. This well-known principle is illustrated mainly for the laboratory stage, where the usefulness of different reactor models is discussed. Particular attention was given to segregation and coalescence.

Theory of Design

The main body of the contributions was extremely varied. The more fundamental papers on reactor design dealt, as a result of the many aspects of chemical and physical nature, with one or two of those aspects only. In this category the paper by Hoffman on the distribution of residence time is perhaps the most useful one for design purposes. Based on as many as 68 references, this is an excellent critical review of today's possibilities in calculative approach to the subject. By its basically physical nature, it is of interest for those concerned with reactor design as well as with construction of vessels for physical operations. Chermin and van Krevelen have given calculated results of reaction kinetics for the consecutive reactions $A \rightarrow B$ and $B \rightarrow C$ at different order of reaction (zero, first and second) and for different ratios of the two reaction rate constants. Their graphical represention is in dimensionless time and concentration parameters. As the approach is purely reaction-kinetical, this paper can be considered as complementary to the one by Hoffman.

Denbigh chose a series of continuously stirred tank reactors as his subject. To his earlier treatment—and for pairs of competing reactions of known kinetics—the optimisation of relative tank size was added. As a further example, the nitration of hexamethylene-tetramine was considered. For reasons of temperature control a number of tanks in series was used, the hexamine being introduced in the second and third vessel as well as in the first. Optimum yield could be obtained in that way.

One of the reactants is introduced at different locations simultaneously in a tubular reactor in the research described by van der Vusse and Voetter, the reactor somewhat misleadingly being called a cross-stream reactor. As with Denbigh's second example, it was found from mathematical treatment that results obtained in this type of reactor could be more favourable than in a stirred vessel or a "normal" tube reactor. No mention was made in this case of the influence of heat of reaction. Pressure and concentration influence only were considered.

Optimum temperature and concentration profiles in tubular reactors without backmixing were the subjects of the paper by Horn, which was more general than the preceding paper. This can be judged from the author's remark, cost estimation from mathematical analyses of different reactors is not yet possible as a result of necessary restrictions in the calculations.

Theoretical Considerations

The papers coming under this heading were in general not applicable to immediate engineering design. Therefore, they will only be referred to here briefly; this does not imply that their value for future use in design is underestimated.

Le Goff *et al.*, in a concise general treatment, drew attention to the influence of physical factors in laboratory-scale chemical studies. Though their treatment is confined to gas-solid contact in different types of reactor, the conclusion that it is impossible to exclude all physical factors from these studies probably applies to other heterogeneous systems as well. Their final remark, that it is not always profitable to exclude physical factors rigorously was supported by other papers referred to in this paragraph.

Asbjørnsen reported on a minute research of residence times distributions in a falling water film. He proposed a double-layer flow model: an outer turbulent layer superimposed on an inner laminar layer.

Kramers *et al.* and Andrew and Hanson both dealt with the dynamics of nitrous gas absorption. While Kramers verified earlier work on the absorption mechanism of N_2O_4-NO_2 mixtures in a laminar water jet. Andrews and Hanson used a sieve-plate absorber to study the absorption mechanism. Their results confirm those of Kramers for high nitrous gas concentrations. At lower concentrations the NO-NO_2 ratio was found to determine the absorption mechanism. Both conclusions together seem to sustain Rietema's views on the importance of engineering background in early investigations.

Reaction Mechanism Theory

Terjesen *et al.* investigated the reaction between calcium carbonate powder and aqueous carbon dioxide, and the inhibiting action of metal ions on this reaction. It is suggested that these inhibitors increase surface concentrations of carbonate ions and thus the reverse reaction. The theory may be general whenever a solid reacts with a liquid containing metal ions that forms less soluble salts with the anion in the solid than the anion itself.

The alkaline hydrolyses of esters was the subject of Viallard's paper. From experiments on this two-phase liquid system, the influence of contact surface as well as the reaction mechanism are explained. A more general approach to the contact between two liquids was presented by Trambouze. Equations are derived for second-order reactions in one of the phases, and for first-order reactions in both phases, both for a stirred tank reactor. When no equilibrium between the phases exists, it is verified experimentally that the ratio between the volumes of the two phases is a parameter.

Van der Held's paper was devoted to the reaction between carbon and oxygen. Notwithstanding a number of simplifying assumptions—mainly with regard to the physical processes involved—the results of his elaborate mathematical treatment agree with experiments.

Jaymond used an alkaline solution, flowing on a slightly inclined plate, to verify theoretical results on CO_2 gas absorption. In that way he evaded complications in liquid flow pattern. The régime could be described as laminar up to Re = 2000, while his experiments were best represented assuming constant CO_2 concentration at the surface, together

with rapid reaction and molecular diffusion in the liquid.

Although no calculation of bed dimensions is given, Schytil and Schwalb contributed to reactor design by giving results on model reactors for catalytic oxidation of sulphur dioxide. The region where over 80% of the SO_2 has already been converted has been considered particularly. It is concluded that in the first part of an SO_2 conversion reactor only the outer catalytic surface is of importance, while near completion of the reaction the inner surface of the catalyst plays a role as well. The subject is treated for fixed beds and fluid beds.

The paper by Youle can in a way be considered to be a first step into the automatic age in chemical engineering design: the use of an electronic machine to prevent errors in human thought, to reject false solutions before they are tested, and this in every single stage of reaction engineering. Examples are given for each of the five stages in process development that show how much mental and manual work can be avoided in this way. Nevertheless, it is clear that chemical engineering research cannot yet be evaded, because it is still necessary to know the influence of physical and hydrodynamical factors that influence the chemical reaction used as a starting point in this technique. It may well be that le Goff's remark on the ever-present physical influences points to one of the major difficulties in the use of the model-making technique proposed.

Design

Although it is recognised that the margin between "theory of design" and "design" is drawn rather arbitrarily, the papers under this heading have, more than the others, design as a direct purpose. A number of them are, in view of their more general theoretical approach, of wider application than the examples they mention. This is obviously so in the paper by Schoeneman on the production of furfurol from xylose. Here the reaction mechanism is determined first from theory and verified by experiments. Next the use of different types of reactor is considered, with and without continuous removal of the desired product (by steam distillation and by extraction). Then the chemical conditions are reconsidered (acid concentration, temperature, sulphuric acid instead of hydrochloric acid). Economic considerations are kept to the forefront and are shown to be of importance in many engineering decisions. The ultimate results have been used for the construction of a pilot-plant scale production unit; and a flowsheet was given. This paper is a clear example of modern possibilities in engineering design, the more so as the reactor has not been considered as a separate item, but as part of the whole process.

High Pressure Polymerisation

The contribution by Hoftijzer and Zwietering on the high-pressure polymerisation of ethylene is another example of modern engineering. By the nature of the process, their study is confined to the conditions in an existing reactor. No mention has been made of the influence of different reactor conditions on the properties of the final product, but under simplified conditions the stability of the steady states in the reactor is considered, stability conditions are derived, and the possibilities of perfect and imperfect control systems are dealt with. Consequently, this paper was one of the very few on the behaviour of a complicated chemical reactor offering mathematical treatment leading to the prediction of a control system.

The paper by Mars is an example of how the behaviour of an adiabatic water-gas shift reactor should be predicted from laboratory research. The results were compared with the actual performance of an existing reactor and a rough agreement found, but the considerable discrepancies still require further investigation. The Shell air-solutiser sweetening process has been discussed by Groothuis. From his study on the kinetics of the process it is concluded that oxygen transfer is the predominant factor in overall reaction rate. Improvement by better stirring is, however, limited for economical reasons. The results are of a qualitative nature, but in agreement with existing theory.

Becker-Boost has contributed to the symposium with a comprehensive paper on the design of ion exchangers. The different conclusions from fundamental theory are dealt with in detail and their use for practical purposes is discussed. A chapter on cost estimation concludes this contribution.

Finally, a number of papers were presented which mainly described reactors for specific purposes. Their interest is therefore less general, although conclusions from general theory are often made. They included Cooper and Lloyd's paper on gas solid reactions in uranium processing—a paper that explains clearly the interdependence of different processing steps—a pilot-plant study on the oxidation of cyclohexane with air under pressure by Steeman *et al.*, the importance of reactivity of cokes in shaft furnaces by Hedden, and Kölbel's report on the syntheses of hydrocarbons from CO and steam in a gas bubble column reactor.

Varied Approach to Reactor Design

From the different contributions, it may be concluded that at this symposium reactor design has been approached along many different lines. Besides, some of the authors, by the nature of the subjects presented, come nearer to design itself than others. But, as Rietema stated in his introductory remarks, each step in reaction engineering—beginning with bench scale research—is of equal importance to the ultimate result. Seen from that point of view, each of the steps has been well covered by the symposium. These different approaches also indicate the present-day trend in chemical engineering. The five-step approach seems to be considered generally as a long and tiresome way to reach ultimate production. In fact, one can conclude from a great many of the contributions that the different approaches all mean shortcuts in this direction: simplification of each step has been proposed by the use of computers; the pure theoretical approach has been discussed; laboratory experiments have been compared with industrial practice; the behaviour of existing reactors has been analysed for future design purpose. None of the approaches has, however, been claimed to be generally applicable, except perhaps the first-mentioned. Therefore, one may conclude from this conference, that reaction engineering still needs a great amount of research before experience and knowledge together create the possibility of predicting the behaviour of production units from laboratory-scale experiments. Therefore, it appears that scaling-up problems, although hardly mentioned, have not been neglected.

Notwithstanding the variety of subjects and the many different opinions expressed at this symposium, the unity of purpose has been clear throughout the meeting. This, of course, must to a large extent be attributed to the care the authors and the symposium committee have taken in their preparations. Thus, the symposium has been an example in itself of the engineering of a great many consecutive reactions under perfect control.

This report was prepared by J. Nijman, Chemical Engineering Department of the Technical University, Delft.

Nomographic Design of Vacuum Installations

A limited number of reprints of the article which appeared on pages 392 to 400 of the June issue of this journal are now available at 3s. each. Applications to Circulation Manager, BRITISH CHEMICAL ENGINEERING, Drury House, Russell Street, London, W.C.2.

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THE ENTHALPY POTENTIAL IN COOLING TOWER AND AIR-WASHER CALCULATIONS

THE Merkel equation,[1] which is used in the design of cooling towers and air washers, expresses the total amount of heat transferred, whether as a result of convection or as a result of evaporation or condensation of water. The driving force in the Merkel equation is a difference of enthalpies (total heats); in the differential form, the equation is written:

$$dQ = \pm K_x (H'' - H) dA \quad \ldots . (1)$$

where Q = quantity of heat transferred (kcal/hr);
K_x = mass-transfer coefficient, related to the difference in moisture content of the air (kg/sq. m. hr);
H'' = enthalpy of saturated air at the temperature of the water surface (kcal/kg);
H = enthalpy of bulk of air (kcal/kg); and
A = surface (sq. m.).

The plus sign in this equation applies to water cooling; the minus sign to air cooling and drying.

The value of dQ is given by:

$$dQ = G_a dH = \frac{1}{k} G_l c_l dt \quad \ldots . (2)$$

where G_a and G_l = mass flow-rates of air and water respectively (kg/hr);
k = correction factor to heat balance[2, 3, 4];
c_l = specific heat of liquid (kcal/kg °C); and
t = water temperature (°C).

From Equations (1) and (2):

$$G_a dH = \frac{1}{k} G_l c_l dt = \pm K_x (H'' - H) dA \quad \ldots . (3)$$

In the integrated form this becomes:

$$Q = G_a (H_2 - H_1) = \frac{1}{k} G_l c_l (t_1 - t_2) = \pm K_x \triangle H_m A \quad \ldots . (4)$$

where the subscripts 1 and 2 correspond to the initial and final values of the parameters, and $\triangle H_m$ is the mean value of $H'' - H$.

A volume coefficient is now defined by:

$$K_{xv} = \frac{K_x A}{V} \text{ (kg/cu. m. hr)}$$

where V, the volume of the apparatus, is given by:

$$V = HA_c$$

where Z is the height and A_c the area of cross-section.

The following equations are now obtained:

$$A = \frac{Q}{K_x \triangle H_m} = \frac{G_a}{K_x} I_1 = \frac{G_l c_l}{k K_x} I_2 \quad \ldots . (5)$$

$$V = \frac{Q}{K_{xv} \triangle H_m} = \frac{G_a}{K_{xv}} I_1 = \frac{G_l c_l}{k K_{xv}} I_2 \quad \ldots . (6)$$

$$Z = \frac{Q}{A_c K_{xv} \triangle H_m} = \frac{g_a}{K_{xv}} I_1 = \frac{g_l c_l}{k K_{xv}} I_2 \quad \ldots . (7)$$

The values of I_1 and I_2 are given by:

$$I_1 = \pm \int_{H_1}^{H_2} \frac{di}{H'' - H}$$

$$I_2 = \pm \int_{t_2}^{t_1} \frac{dt}{H'' - H}$$

and g_a and g_l = weight velocities of air and water respectively, referred to the cross-section A_c (kg/sq. m. hr).

Therefore:

$$\triangle H_m = \pm \frac{H_2 - H_1}{I_1} = \pm \frac{t_1 - t_2}{I_2} \quad \ldots . (8)$$

Various methods of determining $\triangle H_m$ or, of course, I_1 and I_2, have been proposed as follows:

(1) Merkel[1] suggested a complicated graphical-analytical method using an H, t-diagram for moist air, but this has not been widely used.

(2) Dzhanibekov[5] put forward the method of "tabular integration", i.e., the approximate numerical integration of Equation (3), changing the value of the water temperature by 0.5-1.0°C, and assuming for each such interval that the quantities involved in Equation (3) are constant. A similar method has also been used by Spangemacher[6] in applying the Merkel equation to the calculation of cooling ponds.

(3) Steinbach[7] suggested using the log mean enthalpy difference:

$$\triangle H_m = \triangle H_1 - \triangle H_2 / \ln \frac{\triangle H_1}{\triangle H_2} \quad \ldots . (9)$$

where $\triangle H_1$ and $\triangle H_2$ = larger and smaller values respectively of end values of $\triangle H$.

A. A. Gogolin[2] showed later that, since Equation (9) depends on a linear relation between H'' and t, it is suitable only for small changes $\triangle t$ in water temperature (5-6°C). It has also been shown[4, 8] that for large values of $\triangle t$, Equation (9) leads to an appreciable increase in $\triangle H_m$ for water cooling, and a similar decrease when water is condensed.

(4) It has often been suggested that, as in mass transfer, the value of an integral of the form:

$$\int_{x_1}^{x_2} \frac{dx}{x_p - x}$$

where x = potential causing mass transfer; and
x_p = value of this potential at the phase boundary[9] determined graphically. The author[10] suggested determining I_1 in this way, and

[*] Abstracted from the paper by L. D. Berman of the same title published in *Kholodil'naya Tekhnika*, 1960, **37**, 1, 25.

Koch has made a similar suggestion[11] for I_2.

(5) The author has also suggested[10] the use of a modification of Equation (9) so as to reduce the error caused by assuming a linear relationship between H'' and t. This is effected by replacing the appropriate part of the curve $H'' = f(t)$ by a straight line passing, not between the extreme values of the enthalpy of the saturated air H''_1 and H''_2, but displaced towards the x-axis by the quantity:

$$\delta H = \frac{H''_1 + H_2 - 2H_m}{4} \quad \ldots.(10)$$

where H_m = enthalpy of saturated air at temperature $t_m = \frac{t_1 + t_2}{2}$.

Therefore:

$$I_1 = \pm \frac{H_2 - H_1}{\triangle H_1 - \triangle H_2} \ln \frac{\triangle H_1 \mp \triangle H''}{\triangle H_2 \mp \delta H''} \quad \ldots.(11)$$

and

$$\triangle H_m = \pm \frac{H_2 - H_1}{I_1} = \triangle H_1 - \triangle H_2 / \ln \frac{\triangle H_1 \mp \delta H''}{\triangle H_2 \mp \delta H''} \quad \ldots.(12)$$

The plus sign before $\delta H''$ applies where condensation takes place; the minus sign to evaporation.

(6) Koch[11] has made use of Method (4) to construct diagrams from which I_2 can be determined; each diagram corresponds to one particular value of $\lambda = G_a/G_1$.

(7) Lichtenstein[8] has also constructed sets of curves from which I_2 can be obtained, but the curves are for the function $I_2 = f\left(\frac{1}{\lambda}\right)$, while Koch plotted $I_2 = f(t)$. Each of Lichtenstein's diagrams corresponds to a particular set of values of the change in temperature of the water $\triangle t$, the wet-bulb temperature τ, and the barometric pressure. The parameter used for the curves is $t_2 - \tau_1$, while Koch uses the enthalpy H as the parameter in his curves.

(8) Carey and Williamson[12] use a method based on the assumption that the curve $H'' = f(t)$ is a parabola. On this basis, they produced a diagram from which the value of $\triangle H_m$ could be found. A later version of this was evolved by Spangemacher.[13]

Method (1), and even more so Method (3), can be rejected as insufficiently accurate. Methods (2) and (4) give accurate results but are laborious in use. Methods (6), (7) and (8) require the use of special diagrams. Method (5) is the simplest.

That results sufficiently accurate for practical purposes are obtained with Method (5) is shown by the table. The largest error in the value of $\triangle H_m$ obtained from Equation (12) is found in Example 5 of the Table and is about 5%; it is therefore not outside the limits of accuracy of calculations of this kind.

Equation (12) can only be used, of course for water-cooling, when:

$$\triangle H_2 - \delta H'' > 0 \quad \ldots.(13)$$

Examples of Determination of ΔH_m

Operating Conditions	Number of Example				
	1	2	3	4	5
	Water Cooling			Humidification of Air	
Barometric pressure (mm Hg)	745	760	745	760	745
Water temperature (°C)					
Inlet t_1	32.2	36.0	55.0	10.3	20.0
Outlet t_2	23.9	26.0	30.0	17.7	46.1
Mean t_m	28.1	31.0	42.5	14.0	33.05
Cooling range of water Δt_2 (°C.)	8.3	10.0	25.0	7.4	26.1
Enthalpy of saturated air at water temperature (kcal/kg)					
Inlet H_1''	27.0	32.2	86.2	7.1	13.8
Outlet H_2''	17.3	19.5	24.1	11.9	54.5
Mean H_m''	21.7	25.0	46.0	9.4	28.2
Enthalpy of bulk air (kcal/kg) at water temperature					
Inlet H_1	11.6	8.0	13.8	14.4	95.5
Outlet H_2	19.9	18.0	22.1	11.8	16.5
Mean H_m	15.75	13.0	17.95	13.1	56.0
Mean enthalpy difference ΔH_m (kcal/kg)					
By exact method	6.10	12.1*	23.4†	3.56	17.8
From Equation (12)	6.09	12.1	22.9	3.56	18.8

* A value of 12.0 kcal/kg is found from Koch's diagram.
† A value of 22.4 kcal/kg is found by graphical integration.

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Automation in the Chemical Industry

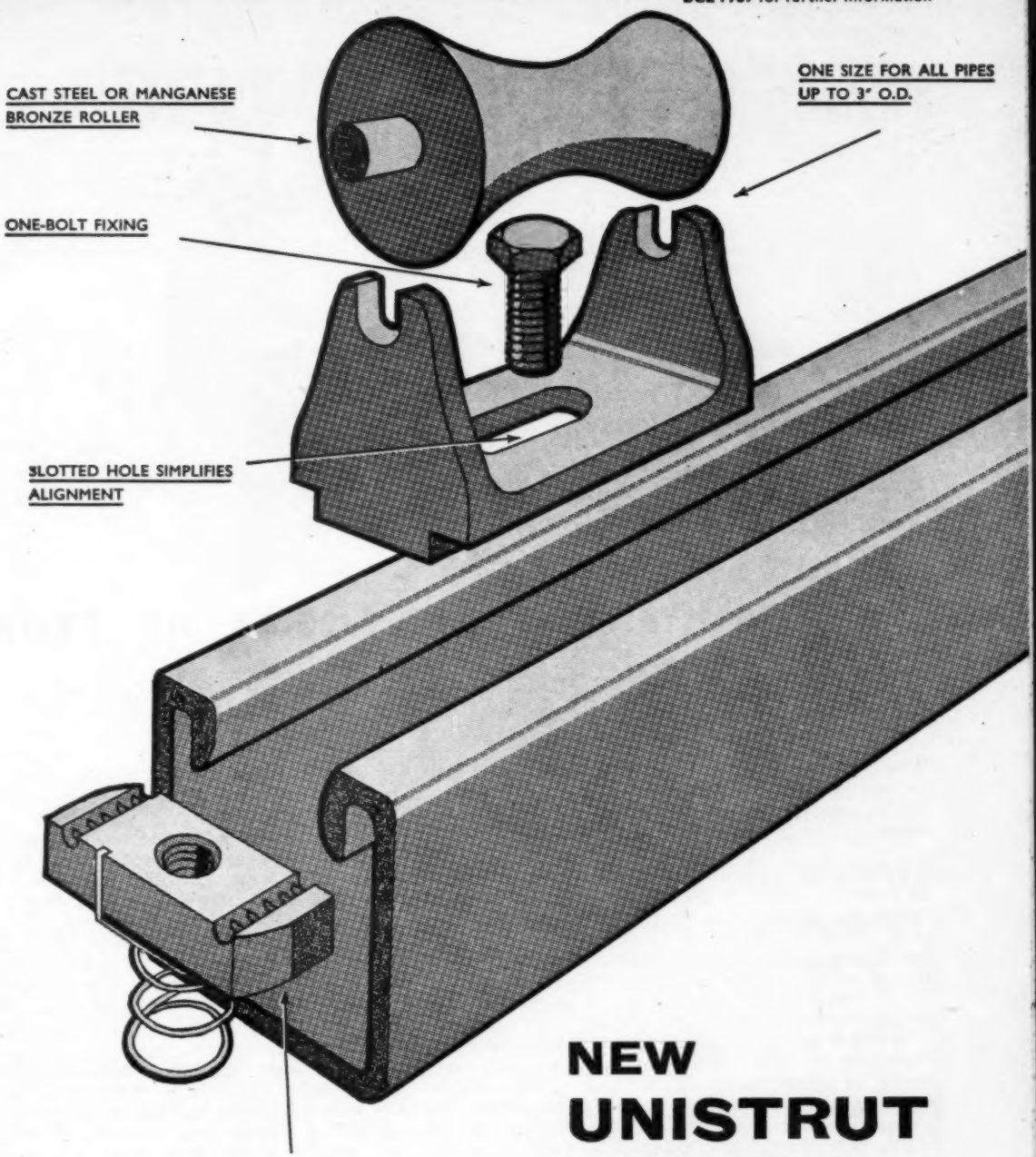
AN EXHIBITION of instruments used in the chemical industry, featuring automation in practice, has just closed at the Birkenhead College of Technology. All the major instrument firms were represented amongst the 44 exhibitors.

One noticeable feature was the increasing use of automation methods of analysis for production control; thus the Baird & Tatlock auto-titrator was exhibited automatically analysing the oxygen content of water. This instrument is designed to carry out the analytical procedure specified completely automatically, and, if required, it will take a sample, perform the necessary operations prior to titration, titrate to end point, record the result in an appropriate form and give an electrical or pneumatic signal for automatic process control.

In the same field of automatic analysis and process control was featured the Hilger Continuous Flow Refractometer. However, these are relatively expensive instruments and the scale of production must be large enough to merit their purchase.

Automation of some of the processes used by the small manufacturer can and must be increasingly explored. Quickfit & Quartz featured an automatic counter-current extraction machine demonstrating the introduction of automation to the simple repetitive operation of agitation, settling, decantation and transfer.

The exhibition was attended by about 500 people in the two days it was open, and enabled local industry to see equipment coming into use in the chemical industry, already a major user of automation in this country.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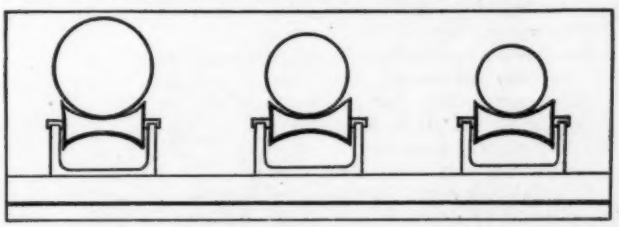

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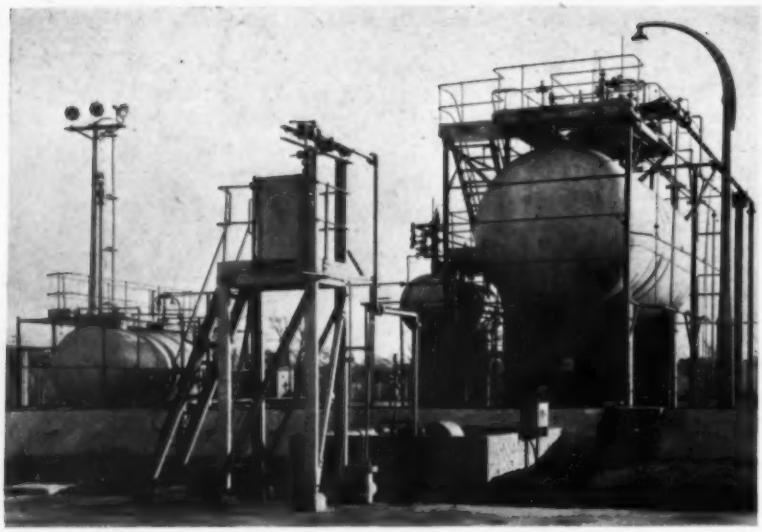


Storage tanks at the Dunlop Rubber Co.'s pilot plant at Fort Dunlop, Birmingham.

SURFACE TREATMENT OF STORAGE TANKS

Which is the cheapest way of protecting butt-welded, mild-steel storage tanks of modern construction against corrosion? In this appraisal "weathering" before painting is recommended

WHEN steel plates are hot rolled at the mill a strongly adherent layer of iron oxides is formed which is known as mill-scale. This layer is hard and brittle. It is rarely continuous or uniform in composition or structure and it is perforated by a multitude of microscopic cracks through which moisture may penetrate. This entry of moisture causes corrosion of the steel underneath the mill-scale and the corrosion is accelerated by the difference in potential of the steel and the mill-scale, the latter being "cathodic" to the steel. From this it is evident that no useful purpose is served by applying a protective coat of paint before removing mill-scale, because the corroding process will continue under the paint film; the paint will flake off and expose an unprotected steel surface. It is therefore necessary to remove the mill-scale.

Methods for Removing Mill-scale

Grit blasting is quite an effective method for dealing with the scale, but expensive and not always practicable because of difficulties of access to tank sites. There is an element of fire risk due to sparks if it is used on tanks containing products of low flash point.

Flame cleaning has the advantage of leaving the steelwork dry and warm to receive paint, but again is expensive, although usually less so than grit blasting. The method obviously cannot be employed in an area where petroleum products are stored.

Pickling has been used extensively in this and other countries for the last 25 years. Pickling of steel by the sulphuric/phosphoric bath system can only be carried out in plant installed at or near the steel mills. The system includes the application of a coat of priming paint to the surfaces of the steel immediately after its removal from the final bath and when the steel is still hot. This is a positive method of removing mill-scale and it is less expensive than the preceding methods.

The rust-inhibiting film of iron phosphate given to the plates during pickling minimises susceptibility to corrosion attack and improves the surface for the adhesion of paint. Life of the paint coating is increased and tends to be limited only by wastage of finishing coat or destruction by mechanical means. The shop coat of primer applied after pickling provides added protection to external bottoms of tanks. In addition, roof trusses and the interior of roof plates are afforded some measure of protection against results of condensation. Finally, the tanks can be painted immediately after erection.

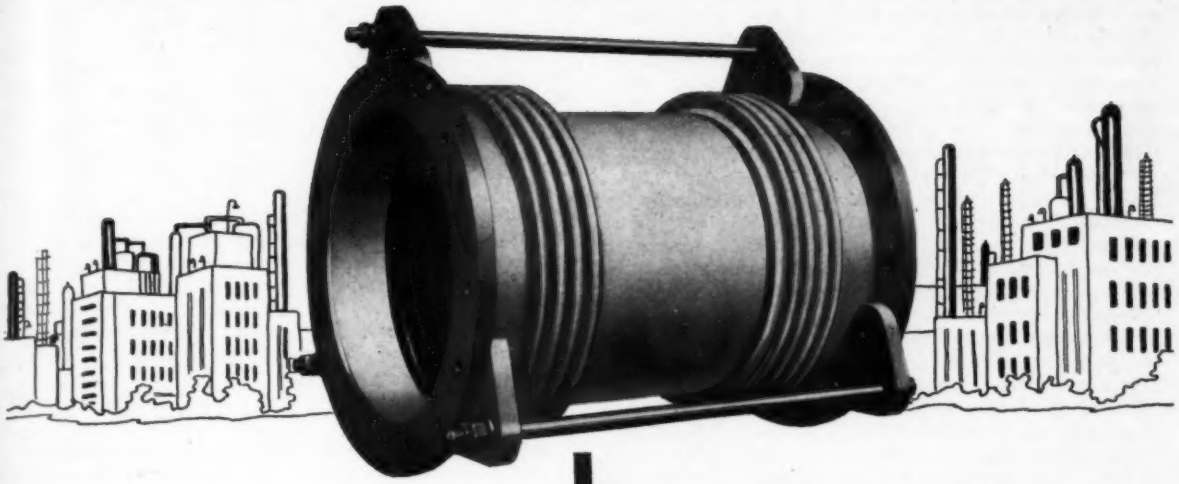
Acid treatment based on the use of acid pickling solutions for removal of mill-scale and rust on structural steel on site has been increasingly applied in recent years. While the application of such solutions may be effective in removing scale and may possibly be economic as compared with other systems, tests with such pretreatments have not been exposed for sufficiently long to determine whether the stability of the subsequent paint system is likely to be affected.

Weathering is the method in which steel is left exposed in order to loosen mill-scale by atmospheric breakdown. During weathering, oxidising and corroding agents penetrate through the mill-scale, which loosens and flakes off to expose a rusted surface on the steel. The period required for weathering of an assembled tank may range from one to two years, according to location and climatic conditions.

Appraisal of Pickling and Weathering

Weathering involves a certain amount of corrosion but this is not likely to exceed 5/1000 in. over a weathering period of 18 months; it does not reduce the strength of the plates beyond the designed stress tolerances. A good standard of painting arrests the corrosion and a tank

The use of **BELLOWS** in Chemical Engineering



Wherever pipes operate under conditions of temperature and pressure, expansion joints may be required. The bellows type expansion joint has in the past few years become standard equipment, being now recognised as extremely efficient. Teddington engineers have played a leading part in the introduction of stainless steel bellows expansion joints to the chemical industry and can be relied on to co-operate fully with design and plant engineers who are confronted with pipe problems.

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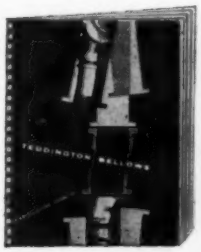

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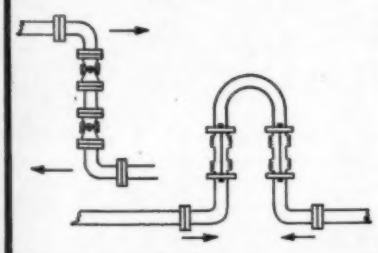

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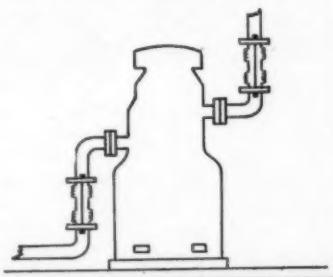

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"weathered" for removal of mill-scale should have a life as long as a tank built of pickled plates, provided protection is maintained by periodic painting. In favour of pickling is the fact that roof trusses and the interior of roof plates are afforded protection by the shop coat applied after pickling. However, this is of limited value, for unless the interior steelwork of a roof is later periodically repainted it reaches a condition similar to that of the interior steelwork of a weathered tank which is unpainted. The shop coat soon deteriorates, especially when certain non-stabilised Middle East crudes are stored in the tanks.

There is similarly a limitation to the claim that the underside of the bottom plates receives added protection by the shop coat of primer when the plates are pickled. In practice, this coat is usually damaged during erection and welding so that unprotected surfaces are laid upon the foundations. In any case, where tanks are placed on foundations having a waterproof carpet of bitumen fix, the possibilities of attack by corrosion are minimised for either method of preparing the plate.

Pickled tanks can be painted soon after completing erection and this feature could influence the large distributing companies who have publicity value to consider. Such companies with world-wide installations situated prominently in public view may find that tanks in process of weathering present an appearance damaging to the prestige of their products.

Cost Comparisons

The following considerations are taken into account in preparing a comparison of the costs based on prices current in 1959.

(a) Pickling and shop-coating the steel for a fixed roof tank of 96 ft diameter × 54 ft high costs £1720. The external area normally to be painted on such a tank is 2874 sq. yd, including an allowance for accessories.

(b) The painting process in all cases is taken to consist of two coats of primer followed by two coats of aluminium finishing paint.

(c) Estimates are based on a period of 25 years.

(d) The priming of a pickled tank with shop coat and subsequent *in-situ* coat provides a protective covering to the steel plates which should last a considerable period, provided the surface is not destroyed by mechanical breakage or receives excessive exposure to the weather due to wastage of the finishing coats. It is assumed, therefore, that the initial paintwork of a pickled tank will last five years and that the tank is repainted thereafter every four years to preserve the protective coating.

(e) The preparation on an unpickled tank would include mechanical wire brushing. Experience at Thames Haven* shows that on average the initial paintwork on unpickled tanks begins to break down during the fifth year and that the tanks then need repainting and again every further four years. Due, however, to the possibility that minute particles of rust or mill-scale may have adhered to the plates at time of preparation of the surfaces, it is found that repainting involves "patch-priming" portions where blistering or flaking has taken place. Therefore, in the estimated costs for repainting of unpickled tanks it is assumed the patch priming would amount to 10% of the total area of the tank. Taking into account costs of material and labour, the painting costs are as given in the table above.

Cost of Painting Tank Exteriors for Storage Tank 96 ft Dia. × 54 ft High

	Pickled tank	*Tank unpickled and weathered*	*Difference*
	£	£	£
First painting	567	862	295
Repainting 5 times	970	1290	320
Total over 25 years	1537	2152	615
Average per year	£61 10s.	£86	£24 10s.

The figure in the last column represents the saving to set against a capital expenditure of £1720 for pickling as noted above under (a). In some cases there may be other considerations than direct cost comparison; for example, it may be considered damaging to the public prestige of a company for their tanks to be seen apparently "rusting" and neglected during the weathering period. Thus, the use of pickled and shop-coated tank plates has other merits, but on purely economic grounds the capital expenditure of £1720 would have to provide a saving larger than £24 10s. a year in order to be justified.

Current Practice

There are wide variations in the practice and experience of the petroleum companies, as can be seen from the following notes:

Site A. At this site the pickling process is adopted but apparently with little success. Twenty-five tanks with pickled plates were due to be repainted three years after the initial painting. Due to the fact that the shop coat of paint was badly damaged at time of erection of the tanks and that the initial paintwork was not of good standard, patch priming to the extent of at least 20% is required on repainting.

Site B. Tanks with pickled plates are not used at this refinery, with the exception of two floating roof tanks recently erected which have pickled plates for the purpose of experiment. The weathering process is generally adopted and tanks are painted within a year after erection. This indicates that either the weathering action is speedier there or that little importance is attached to the complete removal of mill-scale prior to painting. Repainting is carried out at three- to five-yearly intervals.

Site C. Pickling is generally the process adopted at this refinery. There are, however, two floating roof tanks which were unpickled and allowed to weather before painting. The shop coat on the pickled tanks was considerably damaged during erection of the tanks and consequently much patch priming had to be done. Internal surfaces of the shell plates of the two floating roof tanks which were weathered are not painted.

Site D. The policy of this company is for all tanks to have pickled steelwork, shop coated with one coat of red lead graphite. Painting with a second coat of primer and two coats of aluminium paint is carried out soon after erection. The interior of the shell of floating roof tanks is painted, after patch priming, with one coat of petroleum-resisting paint (Australian Blue). Examination of floating roof tanks under erection at present shows that the shop coat of primer receives very little damage.

Conclusion

After careful consideration of the cost data relating to the different procedures and experience of methods used on a number of sites, it was concluded that economic justification for pickling as against weathering cannot be established by Thames Haven.

ACKNOWLEDGMENTS

* Material kindly supplied by London & Thames Haven Oil Wharves Ltd. has been used to prepare this article. We are particularly indebted to Mr. W. A. Beattie and Mr. D. W. Alexander of the Chief Engineer's Department for assistance.

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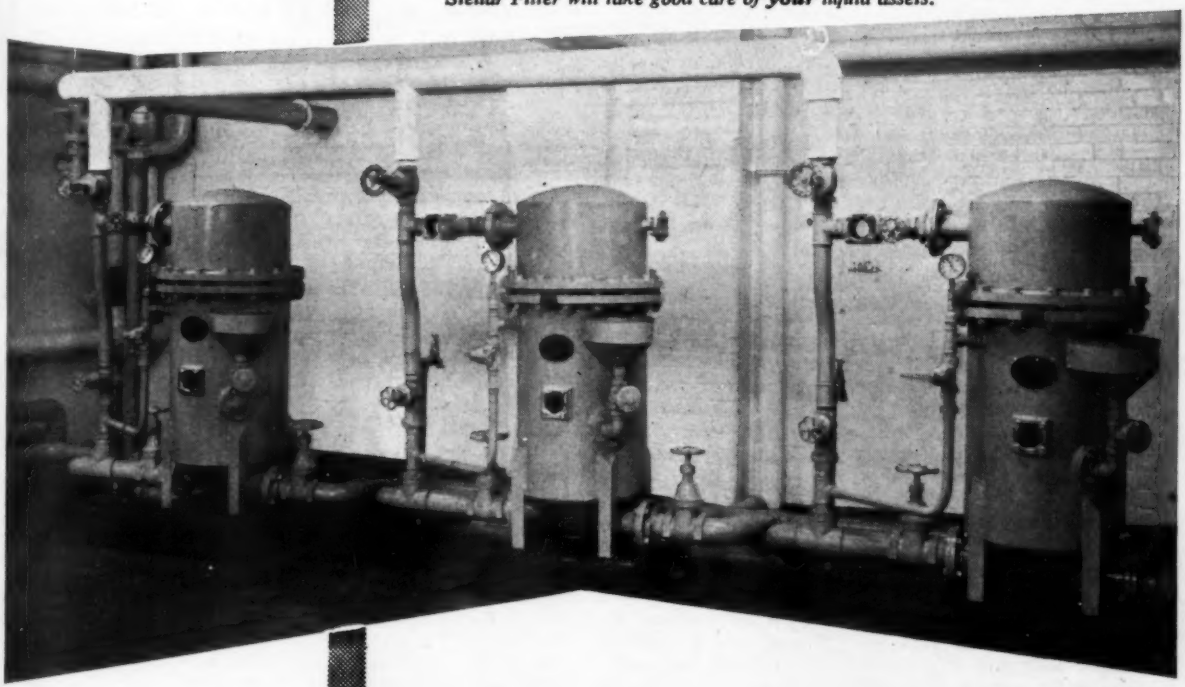

* *They may be: WAXES — OILS ESSENCES—WINES—SPIRITS JUICES—CHEMICALS PHARMACEUTICALS SYNTHETIC RESIN SOLUTIONS SOLVENTS—VARNISHES INDUSTRIAL FLUIDS—and, of course, WATER.*

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AMERICAN LETTER

Changing Concepts in Plant Maintenance

THE growing trend of automation in many United States industries is causing a gradual change in the concepts of production and management. The prime necessity of ensuring the continued operation of complex equipment at optimum levels, plus a steady flow of materials, enforces increased attention on specific plant maintenance functions, such as labour and cost control, budgeting and planning, and the complete or partial use of outside maintenance.

It should not be assumed, however, that the high degree of automation common to many chemical and process plants has led, *ipso facto*, to the highest standards of organisation and operation in every case.

Relative Maintenance Costs

A general survey covering all types of United States industry showed that maintenance costs average about 5.9% in terms of gross property values, about 2.5% of sales and 3.2% of the cost of goods sold. Corresponding figures for the inorganic and organic chemical industries were 5.9, 8.7 and 5.8, while for the heavy process industries the percentages were 5.8, 7.3 and 5.0 respectively. Hence there is no room for complacency or resigned acceptance as regards the relatively high costs of maintenance in these fields, particularly when such costs can approach, or even exceed, the net profit margin. In primary metals—now becoming the province of the chemical engineer to an increasing degree—the reported figures were even higher. Maintenance costs represented 9.6% of gross property values, 6.3% of sales and 8.2% of the costs of goods sold.

However, Carl Wyder, a leading United States authority on this subject, has pointed to the danger of concentrating solely on reducing the reported costs of maintenance, since in some organisations these may already be too low for proper results. Furthermore, the cost accounting procedure used may be giving management a highly distorted view of actual maintenance expenditure. In one case, a detailed check revealed that two-thirds of the maintenance charges could not be properly attributed to maintenance at all!

A survey made a year or so ago by *Factory* supported the view that many United States organisations do not know their actual maintenance costs. Out of 359 plants, at least 5% kept no figures whatever and 25% entrusted their record keeping to the maintenance department only. Where records were kept by the accounting department, 25% of these were not tied into the general ledger. An analysis of cost accounting methods revealed that 10% covered only labour and material costs and 9% subdivided total costs into major accounts for repairs, new work, replacement, etc. Thirty-two per cent analysed via cost centres and 44% subdivided into machine or process operations.

Maintenance departments are handicapped by the absence of realistic cost and cost control data. This emphasises the fact that today's chief plant engineer should be, in part, a cost accounts man as well as a nuts and bolts specialist.

The increasing use of automation has also changed the attitude towards the productivity levels of maintenance operators and their equipment. J. C. Jessen, of du Pont, has reported that since 1945, his company's wage-roll personnel, excluding maintenance workers, has kept almost constant, although productivity in pounds per man has at least doubled. However, the number of maintenance personnel increased 60% during the same period, and in several du Pont plants there are now more maintenance men than direct operators. Hence, maintenance productivity, as well as the quality of service obtained, becomes of prime importance if total production costs are to be minimised.

This factor was stressed by several speakers at the recent Plant Maintenance Conference in Philadelphia, where repeat sessions were held on the use of industrial engineering techniques and practical control systems as the means of raising over-all maintenance productivity. Particular attention was paid to the importance of reducing the non-productive time spent on travelling, assembling materials, waiting for instructions, etc. Various techniques such as time-study, work-estimating, ratio-delay, work-sampling and the use of motion films were discussed, and one session was devoted to incentives in maintenance work.

It is now agreed by progressive United States plant engineers that the usual pleas for not measuring and controlling maintenance operations—e.g., the varied and non-repetitive nature of the work—are no longer valid; these difficulties can, and must be, overcome if future maintenance costs are to be prevented from getting out of hand.

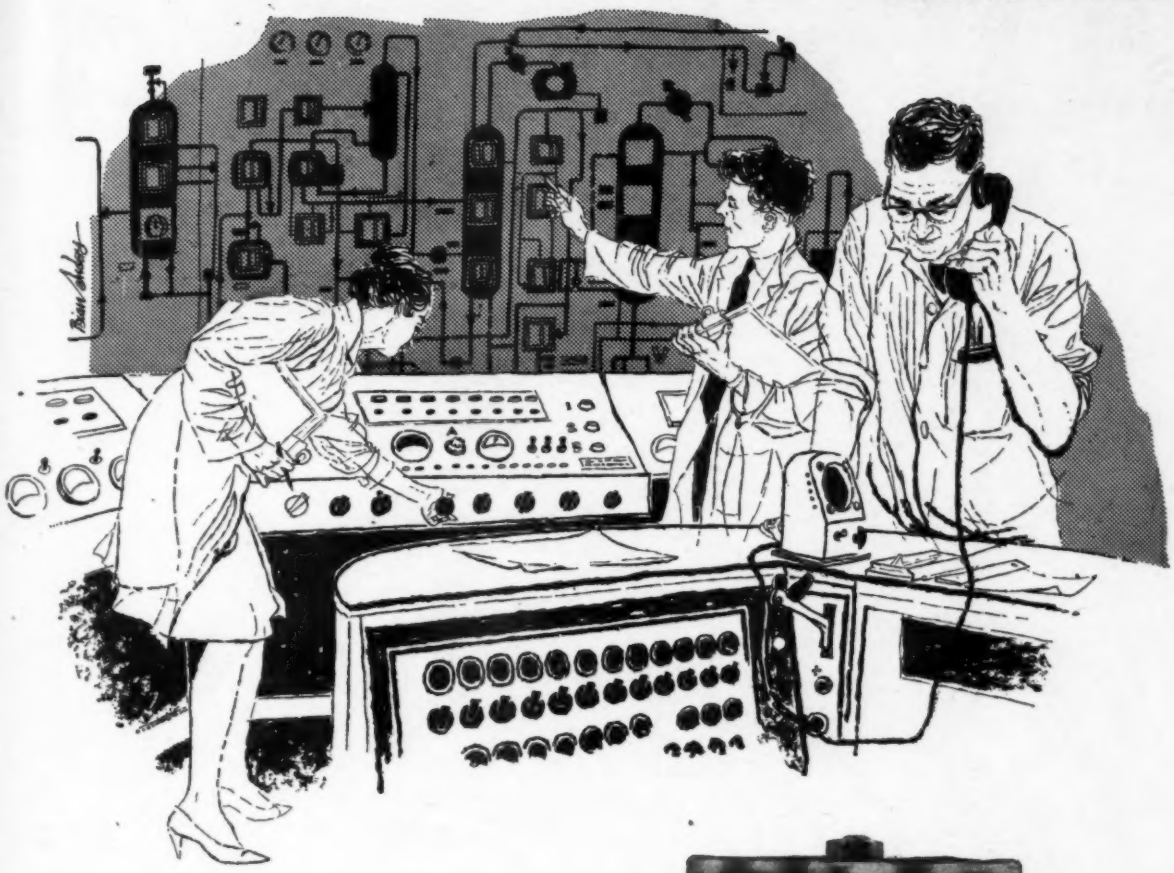
The concept of using outside services to undertake main tenance operations is regarded as an affront by some engineers and as an unworkable idea by others, even though such individuals may have employed this principle for many years. Few plants, for example, service their own elevators, refrigerators or telephones. Still fewer will be able to attend to the complex electronically controlled industrial and business equipment of the future.

In addition to the multitude of contractual services offered in the United States of America, a limited number of concerns undertake responsibility for plant maintenance on a part or total scale, as well as offering assistance during turn-around or other peak periods. One firm reports serving about 20 large clients in this manner and has teams of 25 to 250 men in oil, petrochemical, rubber and cement industries.

This type of service is, of course, a highly specialised job which is often made even more complicated by local labour problems. Not only do seniority rights of plant maintenance personnel have to be considered, but the jealously guarded provinces of different labour unions may create difficulties. For instance, in a large fertiliser company in Florida, the recent introduction of contract maintenance workers belonging to craft unions within the building trades has conflicted with the interests of local maintenance men belonging to the International Chemical Workers Union. This dispute has led to a schism in the AFL-CIO ranks and may create future difficulties elsewhere, until the basic problem is solved.

Large-scale contract maintenance has proved very satisfactory in some new plants, the classic example being the Tidewater Oil Co's maintenance operation, developed and operated by the Catalytic Construction Co. Other suitable fields can be found in heavy industries where major periodic overhauls, expansion schemes or modernisation programmes are undertaken. Contract maintenance is also arousing interest in some areas where skilled craft labour is difficult to obtain, and in organisations where maintenance standards are regrettably low. General experience indicates that it is highly important to examine all existing labour contracts thoroughly beforehand and to prepare very carefully a suitable climate for acceptance and operation. Furthermore, the client should always have an effective escape clause should things unexpectedly degenerate.

BCE 7992 for further information



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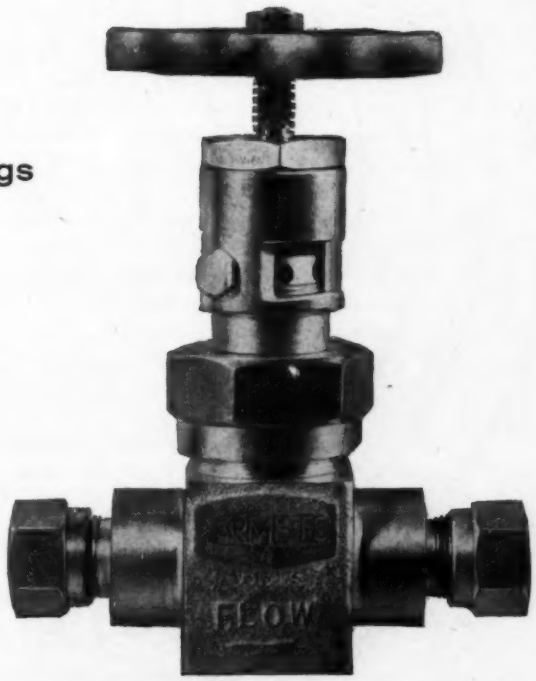

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PHYSICAL PROPERTIES OF CARBON DIOXIDE AT ATMOSPHERIC PRESSURE

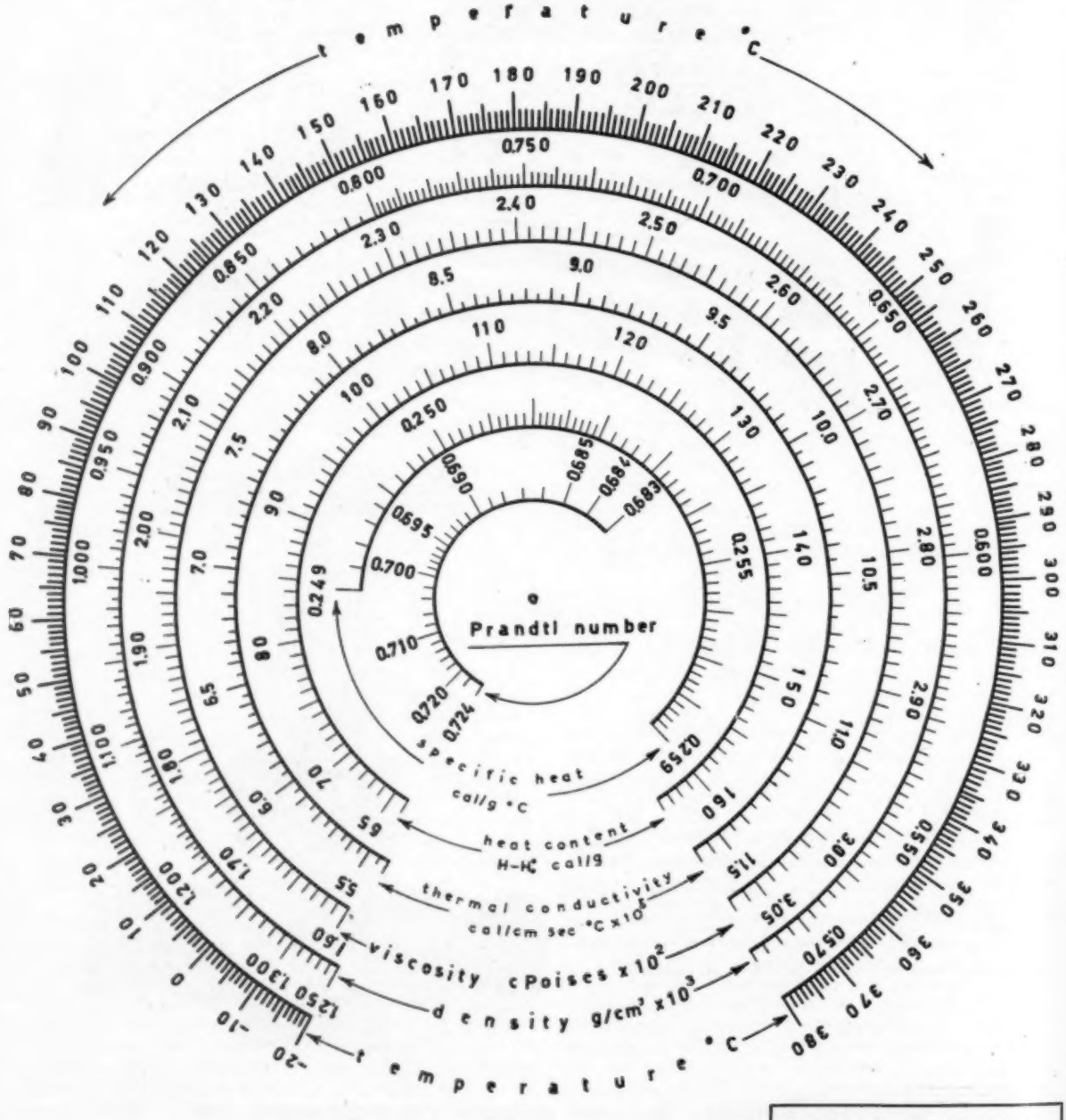
by A. M. P. TANS*

The accompanying nomograph, representing the physical properties of carbon dioxide, has been constructed from published values.[1] The use of the nomograph is as follows. Any straight line passing through the centre intersects the scales at corresponding points.

* Central Laboratory, Staatsmijnen in Limburg, Geleen, Netherlands.

REFERENCE

[1] Hilsenrath, J. E. A. "Tables of Thermal Properties of Gases", National Bureau of Standards, Circular 564, 1955.



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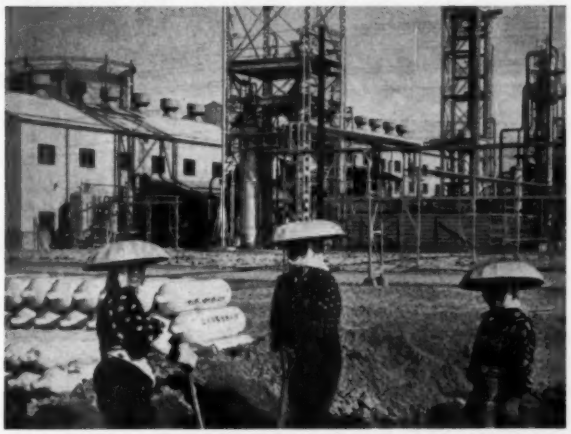

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Book Reviews

Progress in Industrial Microbiology—Volume II
Edited by D. J. P. Hockenhull
Heywood & Co. Ltd., London, 1960, 194 pp., 45s.

WHEN an editor sets out to include in a relatively small volume an up-to-date appraisal of progress in industrial microbiology the difficulty of selection of suitable topics may weigh heavily upon him. In this second volume, D. J. P. Hockenhull has taken the bold step of including contributions on such diverse topics as the Lactobacilli, vitamin B_{12} production from sewage sludge, developments in fermenter design and fermentation control and an article on non-linear problems in statistical and mathematical interpretation. Although it is true that this wide coverage will ensure a greater number of readers, one is left wondering whether it would not be preferable to keep the contribution in each volume in some kind of group order, so that whilst a narrower field might be surveyed the end result would be more advantageous to the reader.

Of the contributions themselves, the statistical paper by J. P. R. Tootil is perhaps the most illuminating. The chapter on biological recovery assay is well deserving of perusal by any worker using biological assay to measure any substance which contains interfering material other than that under test.

R. Elsworth has presented a valuable review of publications on microbiological culture equipment and technology. Perhaps in such a publication it is expedient to remind industrial workers that their writings are lacking in detail when describing the equipment they use. Some excellent advice in terms of small-scale equipment is also contained in the article.

The review articles by J. Postgate on the "Economic Advantages of Sulphate Reducing Bacteria", Hockenhull on the "Biochemistry of Streptomycin Production", Perlman and Sih on "Fungal Synthesis of Citric, Fumeric and Itaconic Acids" and the article by Nivett on the "Microbiological Production of Vitamin B_{12} and Sulphide from Sewage" are excellent articles in themselves and carry good lists of references without necessarily adding anything new to the knowledge of these subjects. The article by J. G. Davis on the Lactobacilli is long overdue and should form a useful addition to the libraries of those organisations using or combating their biochemical activities.

Generally, the book itself upholds the promise of the first volume and leaves the reviewer awaiting with some interest for the next.

G. WILKIN

Symposium on Particle Size Measurement
ASTM Special Technical Publication No. 234
American Society for Testing Materials, Philadelphia, 1959, 310 pp., 45s.

THIS book contains the record of 16 papers and discussions on them at a symposium on this subject held in Boston in 1958. The subject coverage is very limited, but the emphasis is on modern trends, so that this publication augments rather than supersedes the well-known 1941 ASTM publication: "New Methods for Particle Determination as the Subsieve Range."

Methods based on Sieving, Hydrometry, Sedimentation, Light Scattering, Turbidometry, Adsorption and Permeametry are discussed often in rather descriptive terms, but sufficient references lead to relevant ASTM Standards for operational details or to research work for a better understanding of the principles and mechanisms involved.

Wire cloth sieves can now be obtained down to an opening of 25 μ whilst electromesh precision micromesh sieves are available within the range 15-105 μ and are claimed to have reached a precision of 1-2% in the uniformity of the opening. Of the electronic particle counting and sizing machines, several models of which were developed and are being manufactured in this country, only the Coulter counter is described. This machine was only recently introduced into this country. The particles are suspended in a conducting liquid which is made to pass a small aperture where the changes in conductivity of the suspension due to the presence of the particles is electronically recorded. The response is proportional to volume (range $\frac{1}{4}$ to 200 cu. microns) and hence cumulative volume distributions are readily obtained.

The paper on the working of the 1958 ASTM Standard for reporting particle size characteristics of pigments (D1366-55T) has its parallel in the more generally applicable BS 2955: "Glossary of Terms Relating to Powders". The ASTM "particle size parameter" is what the British Standard calls the surface-mean-diameter, the "coarseness parameter" is the 99.5% mass undersize diameter, and the "dispersion parameter" is the ratio of the difference of the 75% to 25% mass undersize diameter, and the surface mean diameter.

There is no possibility of cross-referring subjects as no index is provided. However, the price of 45s. is reasonable.

A.B.C.

Chemical Engineering Education—Academic and Industrial Chemical Engineering Progress Symposium Series—No. 26, Volume 55
American Institute of Chemical Engineers, New York, 1959, 70 pp.

THIS book is a collection of 11 papers on problems of chemical engineering education by a number of authors distinguished in both the academic and industrial spheres of American chemical engineering. The survey covers the changing nature of the unit operation concept, present-day trends in undergraduate courses, the nature and scope of post-graduate work and industrial training after graduation.

A number of interesting features emerge from this work, of which space permits brief mention of only a few. In the unit operation papers the emphasis is on playing down the older physical operations in favour of the "chemical operation". This reflects the ever-growing importance of reactor studies. Moreover, just as the dozen or so unit operations can be reduced to four or five basic physical operations, so can the large number of unit chemical processes be rationalised by concentration on the common content of thermodynamics and kinetics. This approach is reflected in the papers dealing with the development of undergraduate courses where it appears as what may be termed the "chemical engineering science" outlook. Naturally there is emphasis on the need for strong mathematical training. So far there is little that is novel to those familiar with our own chemical engineering education.

However, papers on post-graduate work reveal striking differences, particularly in the way in which high degrees can be obtained through formal study with the "credits" system and written examination. It is, moreover, apparent that there is much argument in American educational circles as to the merits of this system as against the British type of post-graduate research training.

Industrial training does not seem to be developed on such formal lines as has been the case in this country, and it is recognised that training is just as important for the senior man acquiring managerial responsibility as it is for the new graduate.

There is much of interest in this book, but the general impression is that it is only in applying their chemical engineering that the Americans are in advance of ourselves.

D.C.F.

B.S. 3019: Part 2: 1960. General Recommendations for Manual Inert-gas Tungesten-arc Welding. Part 2. Austenitic Stainless and Heat-resisting Steels. 5s.

FORMING ONE OF the process Standards in a comprehensive series, the booklet gives general recommendations for this technique of welding austenitic stainless and heat-resisting steels under normal conditions of manufacture and service. An appendix is included containing notes on the maintenance of the equipment. The recommendations do not apply to joining tubes and pipes and to certain forms of construction; nor does the Standard specify the allowable stresses in welds, or methods for their testing.

"The Engineer" Buyers Guide, 1960 edition. "The Engineer", London 7s. 6d. (plus 1s. 9d. postage).

Although entries are confined to firms advertising in "The Engineer" or the "Buyers Guide" itself, these amount to the considerable number of 1849. Consequently, the Buyers Guide Section of 768 pages contains over 34,750 entries arranged under approximately 2650 classified headings with 1600 cross-references. First of the sections, covering 18 pages, is devoted to chemical plant including both complete plant and accessories. This valuable book is clearly thumb tabbed into its sections which are then largely alphabetically arranged.

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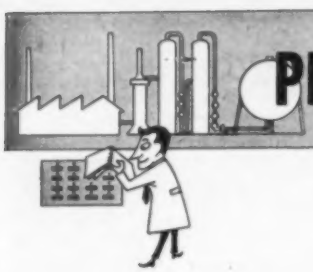


PROCESS ENGINEER'S NOTEBOOK

Controlled Solids Offtake from Cyclones

When cyclones are used for reclaiming process solids from carrier-gas streams, it is necessary to provide a method of removing the solids in such a way that the efficiency of separation is not impaired by allowing solids build-up in the cyclone or by breaking of the gas seal. Lock hoppers, gravity valves and rotary valves are examples of methods which have been employed for solids offtake control. The lock hopper method suffers from the disadvantage, when speedy removal of the solids is required, of being a two-stage operation; gravity valves can be affected to some extent by changes in pressure drop across the cyclone (i.e., those caused by loading fluctuations); rotary valves may be subject to seizure or blockage especially at higher temperatures or if the solids tend to agglomerate between the vanes.

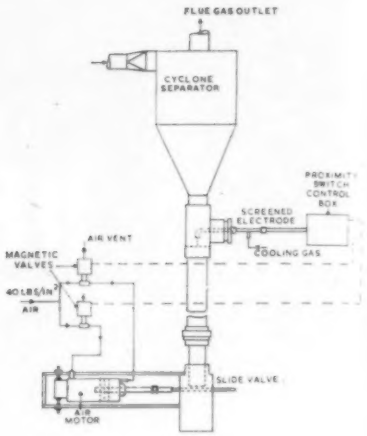
In an experimental process plant a cyclone was used as a reclaiming unit for −10 mesh process solids at temperatures in the range 400-600°C. It was especially important that the solid be removed from the cyclone as rapidly as possible for both steady and fluctuating load conditions without releasing the gas seal or allowing the solids to build up.

Fig. 1 shows an arrangement for solids removal which has been used successfully. The basis of the method was to maintain, as closely as possible, a constant level of material in an extended cyclone tail leg. The lower end of the tail leg was provided with a specially made "non-stick" slide valve whose details are shown in Fig. 3. It was operated by a two-way air motor which was connected to 40 psi air supplies via two three-way magnetic valves.

A gas-cooled electrode (Fig. 2), coupled to a proximity switch box which supplied current for the magnetic valves, was introduced into the tail leg near the top to detect the level of solids. As the level rose or fell, the appropriate magnetic valve was energised, so opening or closing the slide valve. At first an ordinary screened electrode had been used for detecting the solids level, but it proved to be unreliable with the solid at the temperatures used. A gas bleed was introduced with the twofold purpose of cooling and cleaning the electrode and was found to have the desired effect.

W. H. Newton and G. O. Davies

Fig 1.



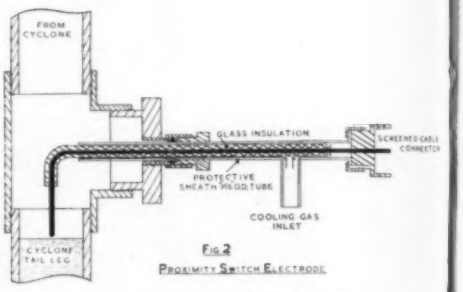


Fig 2
Proximity Switch Electrode

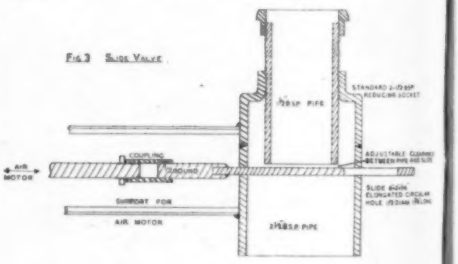
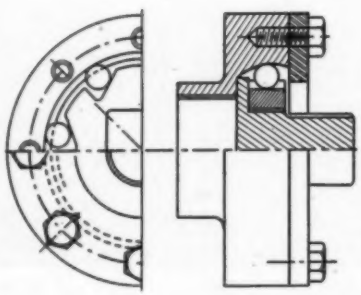


Fig 3 Slide Valve

A Simple Flexible Positive Agitator Drive

A problem of peculiar difficulty in the chemical and extractive metallurgical industries is that of slurrying a deposited solid in a tank with some liquid; and often it is also necessary to blend in another solid with this slurry. It is generally advisable to avoid the use of a footstep bearing for the agitator in such instances, since this type of bearing rapidly becomes useless through abrasion due to the solids; but if one attempts to dispense with the



bearing one usually finds that the agitator is forced out of the solids by the resolved forces. Several methods of overcoming this are used, including the use of either (a) external bearings spaced at a distance apart equal to the overhang of the agitator shaft or (b) use of a universal coupling enabling the agitator to rack over the solid and gradually bring this into a suspension.

Although the standard universal coupling is quite satisfactory it is not

always positive enough, so something better is usually necessary. The sketch outlines a simple coupling designed to overcome this. The positive drive is provided by the balls locking by wedge action against the track; reversing releases and permits the coupling free-wheeling. Flexibility is provided by the self-aligning track. Some of the thrust from the agitator is taken on the balls via the thrust face provided in the coupling, but the weight of the agitator must be carried by the main-motor thrust bearing.

F. MOLYNEUX

Mist Eliminator

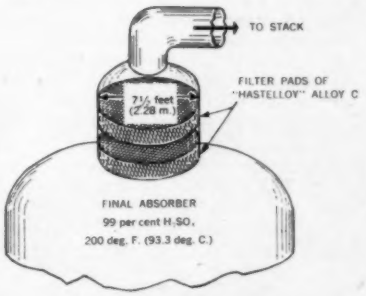
VARIOUS SOLUTIONS HAVE BEEN applied to the problem of arresting the mist formed during the final absorption stage in oleum manufacture, one of the most recent being to fit mats of fine wire mesh at the top of the final absorber. At one plant, the mesh material employed was 0.30-mm diameter wire of Hastelloy C (Ni 54, Co 2.5, Cr 15.5, Mo 16, W 4, Fe 6, C 0.08). Filters made from this material proved capable of removing all but the very finest of droplets from the exit gases, effectiveness being ascribed to the scrubbing action of a layer of liquid held within the interstices of the filter mesh. To establish this condition requires operation within the correct range of velocities. It has been found that a two-stage filter will reduce the acid content of the absorber exit gases to 1 to 2 mg. per cu. ft for a pressure loss of no more than 1½ to 2 in. water gauge. The pads are 6 in. thick and 7½ ft in diameter and they have for 2½ years resisted the action of 99% acid at a temperature of 93°C. The arrangement allows maintenance to be carried out during the normal six-monthly inspection periods, an important advantage, for not only is the particular installation an awkward one to service, but the entire unit would have to be shut down in the event of a filter failure.

Another reported use of the above alloy is in the production of mixed fertiliser. The material is used for spray pipes through which are passed sulphuric acid in the one case and anhydrous ammonia in the other. Both pipes, which feed liquids to a mix of superphosphate and potash in a drum granulator, are continuously submerged in the wet solids.

According to previous experience, black iron pipe used to distribute the liquids failed after only 1000 tons had passed through the drum granulator. High alloy steel gave a ninefold improvement on this figure, but this was still not satisfactory enough. The corrosion caused primarily by the sulphuric acid caused the sparger holes to become enlarged in a short space of time, with the result that not only was there a considerable waste of sulphuric acid and nitrogen, but also frequent replacements were necessary. Two hours down time were required for replacement.

At present the replacement nickel alloy pipe has already allowed 25,000 tons of fertiliser to be processed in the granulator without any appreciable sign of deterioration of the spray pipes.

(Haynes Alloys Digest, *February* 9, 1960.)

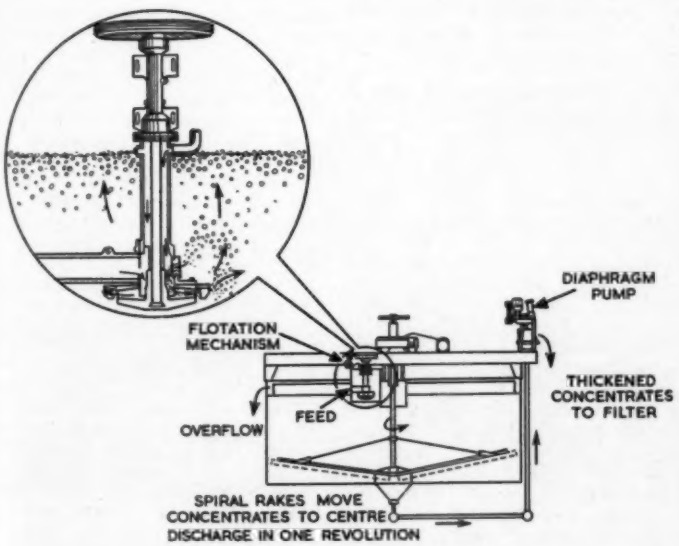


Froth Breaker for Concentrate Thickener

THE PROBLEM OF FROTH FORMATION at concentrate thickeners can be overcome by installing a flotation mechanism of the type shown in the encircled diagram. The additional mechanism traverses the entire width of the thickener and in so doing draws in the froth present on the surface of the slurry. The standpipe of the flotation mechanism is closed to exclude atmospheric air, and an enlarged feed pipe is provided in order to allow the free entry of the voluminous froth.

The combination of conical impeller and wearing plate, which the standard flotation machine provides, offers an effective froth-breaking device, since the suction action of the machine breaks down the froth by pressure change. Flotation machines of this kind may also be used before a filter if thickening is not necessary.

(By courtesy of Denver Equipment Co. Ltd.)



Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

Book Reviews (continued)

Chemical Engineering Practice: Volume XI—Works Design, etc.
by Cremer and Watkins
Butterworths Scientific Publications, London, 1959, 390 pp., 100s.

THIS volume in the series of twelve is a sincere attempt to present in a concise form the complex problems inherent in the design of a works and its subsequent operation. In the limited space available, the authors have attempted to lay down guide lines and have succeeded in bringing together a large number of check points which are useful to the designer and operator alike. It is unfortunate that out of 390 pages, packed with information and interest, only 78 have been allotted to works design. This is a subject in which every chemical engineer is engaged directly or indirectly at some stage of his career and about which all too little literature has so far been published. In fairness, it should be stated that design practices would require a manual for effective treatment.

For the success of any project the design plan must be soundly conceived and executed. In this, the human factor is the all-important link which makes all things possible within the limits of knowledge, experience and finance. For success a strong team must be created and soundly led. In the U.K. alone, millions of pounds are annually invested. A poor plan not only means that investment capital lays idle and money is wasted, but time—the major enemy from design through to completion of a project—is lost and so delays the launching of new products or increased supplies to the market.

The authors rightly lay stress on the importance of the planning stage. The decision to build a plant is arrived at as a result of integrated functions, technical, commercial and financial, after careful study. Only by the preparation of a master plan and its ruthless execution can a new project be accomplished in minimum time for minimum cost.

The chapter on civil engineering and its design relationship to the project is of importance, but it should be remembered that civil works only account for some 8-25% of the overall investment. It is unfortunate that a separate chapter has not been included showing the manner of tying together all the unit equipment which constitutes the plant, its layout and relationship to the civil side. The use of buildings, whilst necessary for certain processes, has decreased in the post-war period. This trend has been dictated by economics and the successful use of automatic instrumentation, which has greatly reduced the number of operators.

Chapter 3 gives a very useful summary of the various contractual arrangements which are possible for the handling of a project. All the methods reviewed have their merits, but, speaking from personal experience, a prime cost contract is the least desirable. Every contract should aim at providing some incentive to the contractor. This can be achieved by lump-sum contracts, usually at the expense of time unless the design can be pulled out of the bottom drawer. Alternatively, a contract can be negotiated into a lump sum as soon as the design has progressed far enough and the risk of major process changes have been reduced or eliminated. This method has a great deal to commend itself, particularly where the process is new and bristles with development, as it avoids the two to three months necessary for competitive lump-sum tendering and allows the appointed contractor to be brought into the job at the earliest stage, preferably in the process design period. Of the four types of contract referred to on page 50, the first three are, in general, only applicable to civil contracts. It will be a useful development, as times go on, to see greater use made of scheduled rates applicable to mechanical contracts.

The chapter on Construction and Installation provides an insight into the preparation of construction schedules, cost control and reporting. The average chemical engineer tends to neglect this most important side of his work. It is important that busy management should have a clear and concise picture of what goes on and the extent at any time of physical and financial progress, commitments and estimates to complete. It is the duty of a properly organised project to see that this type of information is constantly provided.

The concluding chapters on Works Administration, Factory Legislation, etc., provide a valuable collection of data and ideas. So much has been written and published on these subjects that it would be imprudent to go into detail. Nevertheless, a few points stand out. Every person engaged on a works should know what his function is, have his responsibility and authority properly defined and be made to feel he is a part of operations.

Where major construction is taking place side by side with existing operations, it is beneficial if construction be split off and handled by a specialist group, so freeing site management to concentrate on operations.

In spite of the foregoing comments, it can be said that this volume is worthy of taking its place with others in the series.

J.H.S.

Laboratory Instruments, 2nd Edition
by A. Elliot and J. Home Dickson
Chapman & Hall, London, 1959, 514 pp.

TO provide a guide to workers called on to design and construct instruments or to supervise others in their construction is the aim of this book. It presents the principles on which good design is based, and gives many examples of their application. No attempt has been made to cover the entire field of instrument design, but the authors have endeavoured throughout to show the inter-relation of good design, material and method of construction, so that the best results may be obtained with moderate or limited means. A final chapter deals with the applications of photography and there are several appendices containing miscellaneous information.

Gas Purification
by Arthur L. Kohl and Fred C. Riesenfeld
McGraw-Hill Book Co. Ltd., London, 1960, 556 pp., 116s 6d.

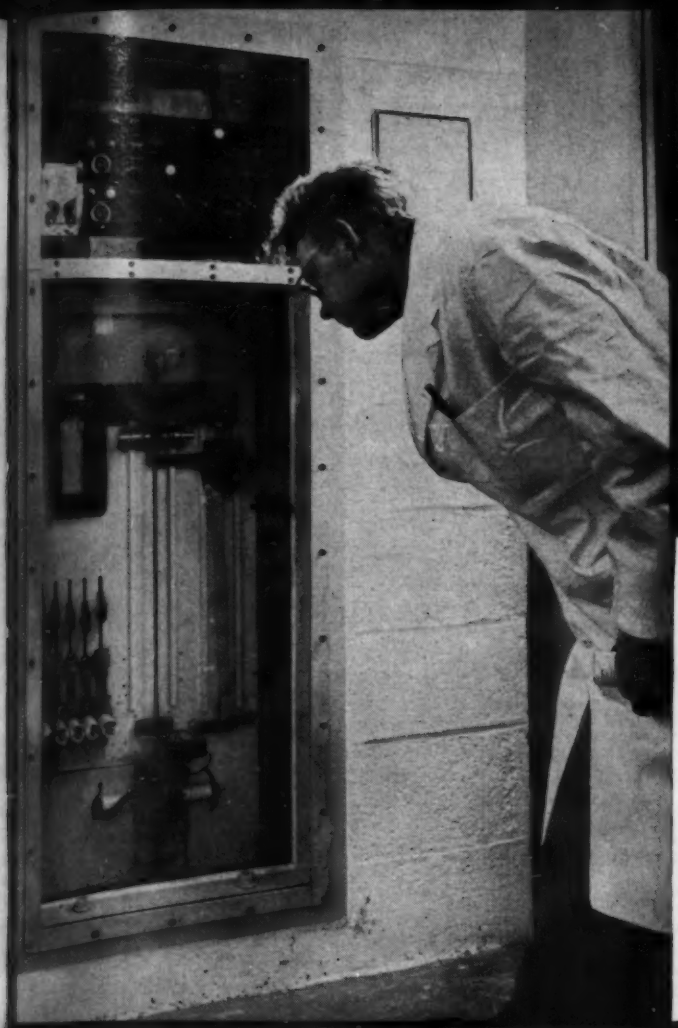
THIS book deals with the removal of vapour phase impurities, which are present in gaseous streams in minor proportions, by means of absorption in liquids, adsorption on solids or chemical conversion. It is intended to provide a practical description of processes and techniques concerned with gas purification and dehydration.

The basic theory is restricted to a short outline of absorption and adsorption, the two unit operations around which the various processes are centred. The contents include a description of processes for the removal of SO_2 and H_2S by means of ethanolamines; ammonia and alkaline salt solutions; gas purification using water as an absorbent; SO_2 absorption in liquids; wet and dry oxidation processes for removal of H_2S and other sulphur compounds; absorption of basic nitrogen compounds and dehydration. Also described are processes based on the catalytic conversion of gaseous impurities, e.g., catalytic oxidations and reductions, shift conversion of CO to CO_2 and methanation and miscellaneous gas-purification techniques, e.g., low-temperature separations and absorption of hydrocarbons in oils and absorption of CO in copper-ammonium solutions.

The book is well illustrated with graphs and flow diagrams and is full of design and operating data and know-how, some of which is available in the literature and some new provided by the various plant manufacturers. There are numerous references and it is encouraging to see that the existence of chemical engineering literature on this side of the Atlantic is recognised in an American publication. This is a comprehensive reference book bringing together a vast amount of information on the most frequently used techniques and processes in gas purification. In many instances complete performance data and operating experience of existing plants are included. Materials of construction and corrosion problems pertaining to these processes are also discussed. In addition, plant and operating costs (for U.S.A. conditions) are given in some cases and these, with the use of suitable equivalents, can simplify the choice of an economic process. This is particularly valuable, since most of these cost data are derived from full-scale installations.

Perhaps some of the chapters appear to be a collection of manufacturers' literature lacking sufficient critical comment from the users' point of view. Also, some of the processes described may be a little out of date, but the face of chemical industry is changing continuously and often old and long-discarded processes are rejuvenated to flourish under a new set of conditions. This book will be welcomed by engineers interested in the design and operation of gas purification plants.

T. A. KANTYKA



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PLANT EQUIPMENT NEWS

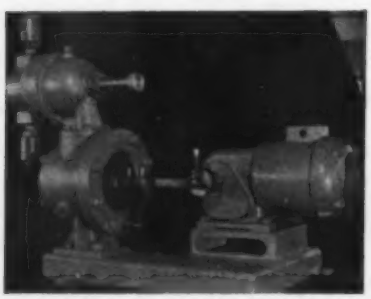
Temperature Indicators and Surface Markers

Over 60 different temperature calibrations from 113°F to 2000°F are now available on Thermomelt temperature indicators. These are based on determining the temperature on any surface being heated by watching the melting action. The surface is marked with the stick or liquid or a pellet placed on the surface. When the surface reaches the desired temperature, the mark or pellet quickly liquefies. It is claimed to be accurate within ±1% of stated temperature; this method in many cases is more accurate than a surface pyrometer. It makes positive contact with rough, corroded or curved surfaces, thus assuring a true reading, while a surface pyrometer under these conditions may give an incorrect reading. The pellets are intended for use where prolonged heating is necessary. These pellets are a simple and inexpensive means of checking for proper functioning of thermocouples within a furnace. Liquid can be applied to any type of surface, particularly that of intricately-shaped parts where other temperature-measuring equipment is not feasible. The same company make a so-called Painstik, which can be applied to the surfaces of metal, lumber, glass, plastics, rubber, ceramic articles and to fibrous materials. **Markal Co., West Carroll Avenue, Chicago, 12, Illinois.** *British Agents:* **A. Levermore & Co. Ltd., Haynes Lane, Kenley, Surrey.**

BCE 8028 for further information

Bellows Pump

A new design of bellows pump for the transfer of small quantities of acids and corrosive liquors has recently been introduced by L. A. Mitchell Ltd. The action of the pump is achieved by the deflection of a closed P.T.F.E. bellows which is actuated by the reciprocating diaphragm pressurising an oil reservoir. The acid or liquid end of the pump and the bellows are the only parts of the pump coming into contact with the liquor being pumped. Liquid ends can be supplied in a variety of materials such as cast iron, stainless steel, Monel, P.V.C., P.T.F.E. or chemical stoneware, according to the properties of the liquid being pumped.



Liquid ends are fully interchangeable and a variety of liquid ends can be held in stock to be fitted to the pump as required. **L. A. Mitchell Ltd., Harvester House, 37 Peter Street, Manchester, 2.**

BCE 8029 for further information

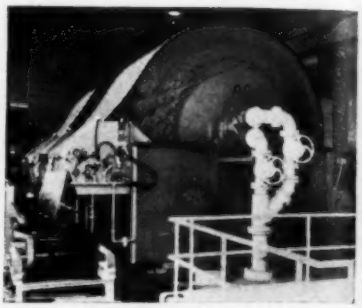
Stainless Steels

Two new stainless steels have recently been introduced by Samuel Fox & Co. One of these, Fortinox, has been developed specifically for use in the production of clock and instrument springs. It is said to be unbreakable and to show no loss of power during service in the lifetime of any mechanism in which it is used. The other steel consists of a new range known as the Jethete series. Jethete M151 is a low-carbon 12% Cr-Ni-Mo-V steel, in which the composition is controlled so that the structure is fully austenitic at solution and welding temperatures. Jethete M152 is a development from M151, having a similar composition but with high impact properties and a low transition temperature. Other steels in the range are available for intermediate properties or for use at higher temperatures. **Samuel Fox & Co. Ltd., 17 Westbourne Road, Sheffield, 10.**

BCE 8030 for further information

Filters

In the new Eimcobelt filter it is claimed that blinding is eliminated. This is a movable cloth filter using an entirely new principle of cloth alignment and is recommended for handling difficult slurries continuously. It is an adaptation of a conventional vacuum drum filter in which the filter medium is removed from the drum every filter cycle and passed around a small-diameter discharge roller. Cake breaks cleanly and completely from the filter medium when the cloth is suddenly subjected to the sharp change in radius of curvature of the discharge roll. The flexing of the cloth tends to extrude cake lodged in the interstices of the cloth weave. In effect, the manufacturers say, the cake discharges itself without air blow or scraper blade. After cake discharge, the filter medium passes through a washing zone employing jet sprays. Here the medium is thoroughly washed, front and back, with either periodic or continuous wash sprays. Chemical washes may be introduced through the spray pipes. It is claimed that cloth always returns to the drum completely clean, so that filtering efficiency and rate are maintained due to the absence of blinding. The same firm has also developed an adaptation of the conventional filter press to overcome the need for hand cleaning at the end of each filter cycle. In the adaptation the frames can be swung away from the filter plate bearing the cake while a fresh set of frames swings into position and a new filtration cycle begins. The plates are



pneumatically pressed against the frame and are said to be perfectly sealed. Slurry is fed in from the bottom, fills the frames and the filtrate is blown through under pressure. The cake is washed and the wash water blown through, then the cake displaced from the filter medium by a reverse blow. Vacuum is applied to separate the plates from the frames and the latter swing away. While the cake is being discharged from these, the new filtration cycle begins. This type of filter, known as the Eimco Burwell, is already in use in the U.S.A. and is now being introduced into Britain. It is probably most useful for filtering with short cycles, for a constant feed and where good washing efficiency is required. **Eimco Ltd., 190 Piccadilly, London, W.1.**

BCE 8031 for further information

Liquefied Gases Pump

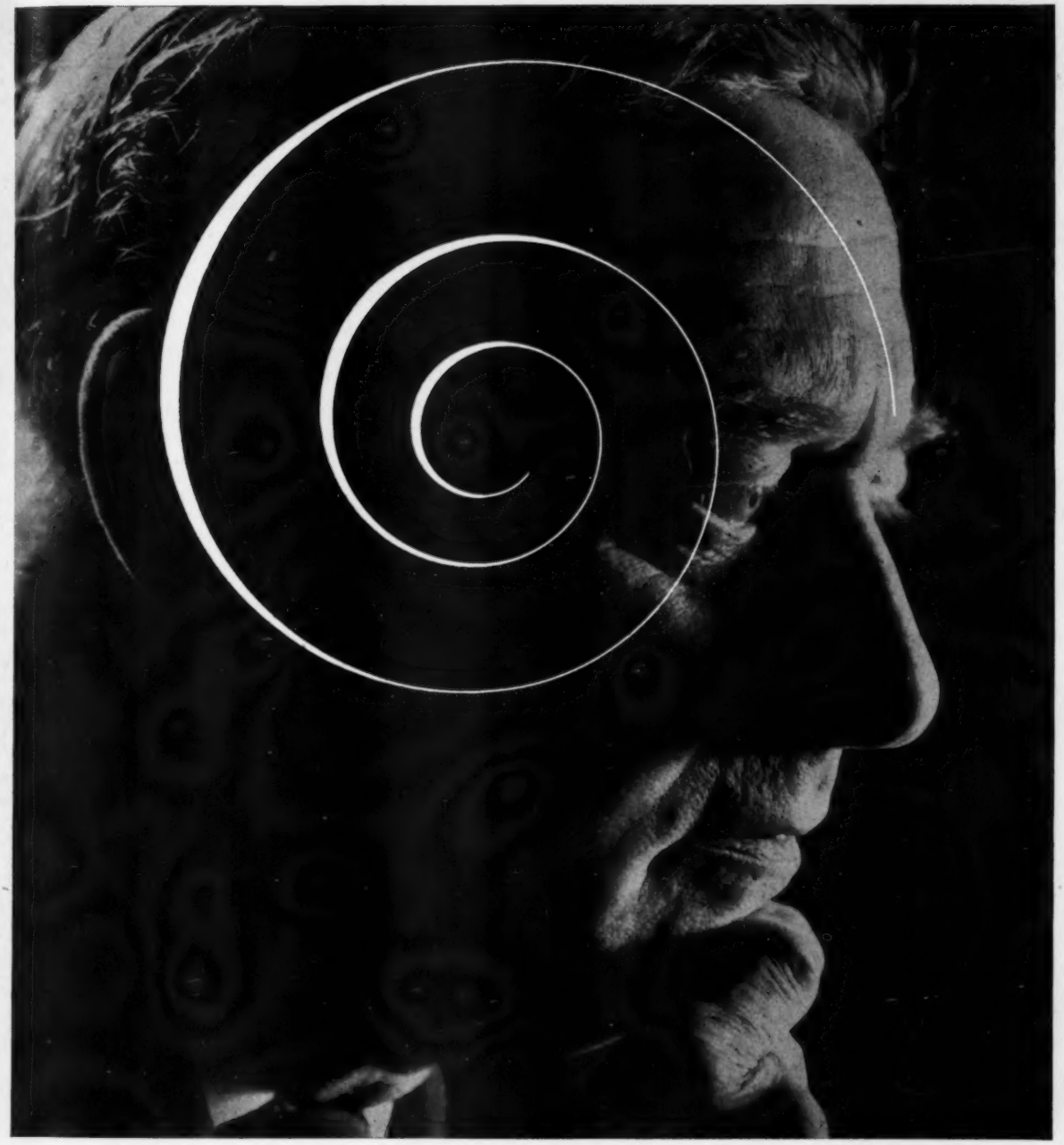
The introduction of larger models to their range of pumps for liquefied gases is announced by the Distillers Co. These comprise two standard sizes: one to pump up to 100 gph at a pressure of 1000 psi, the other of double this capacity. The whole of the diaphragm head unit and hydraulic actuating unit is built into a steel-framed casing finished in grey hammer tone enamel with the control and instrument panel forming an integral part of the unit. The refrigerating unit is supplied as a separate component fitted outside the pump casing, as its capacity and temperature characteristics depend upon the temperature at which the liquefied gas has to be pumped. **Distillers Co. Ltd., Great Burgh, Epsom, Surrey.**

BCE 8032 for further information

Cone and Plate Viscometer

The Ferranti/Shirley cone and plate viscometer, which is said to be particularly suitable for studying the anomalous flow behaviour of the more complex fluids (which can often only be characterised satisfactorily by means of flow curves in which apparent viscosity is plotted against rate of shear or shearing stress), has now been modified to incorporate an automatic flow curve recorder. **Ferranti Ltd., Hollinwood, Lancs.**

BCE 8033 for further information



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PLANT EQUIPMENT NEWS

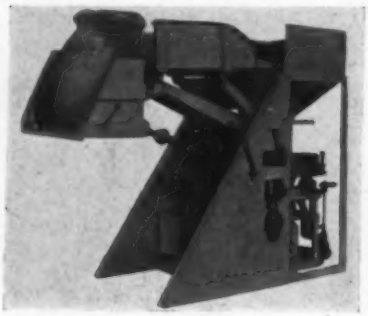
Miniature Oven

A recent addition to the Isopad range of electric heating apparatus is a micro oven with a cavity of 4 in. diameter and 4 in. deep. Temperatures of up to 300°C are obtainable, and the equipment has a ventilation rate of 150 changes or 112 l. of air an hr. **Isopad Ltd., Barnet By-pass, Boreham Wood, Herts.**

BCE 8034 for further information

Sack or Drum Manipulation

This equipment has been designed to lift and tip sacks, drums, bins, etc., and can be moved close to the receptacle into which discharge is to be made. Two lifting arms operated by independent hydraulic rams lift and tip the hopper holding the container. The drive is by a 3-hp 1425-rpm electric motor, coupled direct to a hydraulic pump.



The machine, which weighs approx. 5 cwt, can handle up to 6 cwt and will discharge at heights from 3-8 ft. The unit can be supplied on wheels. The steel hopper, equipped with valve, is bolted to the main frame. Quick-release screw clamps are provided for holding the drum, bin or carton in position, and for sacks a special retractable steel claw is provided. Pre-lubricated self-aligning bearings are used throughout and very little maintenance is required. The unit is of robust construction, silent in operation and capable of continuous 24-hour duty. **Russell Constructions Ltd., Russell House, Adam Street, London, W.C.2.**

BCE 8035 for further information

Diverter Valve

A diverter valve now being manufactured by Thomas Robinson & Son Ltd. is designed for use with the company's Pneu-Flow pneumatic conveying system, for diverting powdered or granular material in blowing lines.

It can be supplied for either manual or electro-pneumatic operation, in various bore sizes, and single solenoid valves with spring returns, or double solenoid valves which can remain in either position indefinitely, are available. An adjustable cushioned end-cap is fitted to valves required for very high-speed operation, and a solenoid control valve is also available which allows air to enter the cylinder at a faster rate.

The piston of the valve is moved by compressed air, admitted through the end-caps. A piston valve, electrically operated by a solenoid, admits compressed air from the air-line to the required cylinder end, and in the same operation exhausts the air from the opposite side of the cylinder. Air pressure required is 60 psi.

The valve is being included in both small plants and fully automatic plants of the type which the company is now installing. **Thomas Robinson & Son Ltd., Rochdale, Lancs.**

BCE 8036 for further information

Heated Hoses

To maintain liquids at required temperatures during pumping, two special forms of hose have been introduced by Heated Hoses Ltd. These make use of conventional metallic strengthening materials in the hose walls and do not incorporate separate heating elements.

Heronflex, as one is called, has two concentric metallic braidings which are used to give flexible hose a high mechanical strength to withstand hard usage. As this braiding comprises a large number of wires, heat is applied over the whole area by means of a current of sufficiently low voltage to avoid possible risk of shock.

The braidings are electrically connected at one end and at their other ends they are connected to the secondary winding of a mains transformer. The greater concentration of heat is applied at the inner surface of the hose by making the inner braiding of high resistance steel and the outer braiding of copper so that there is a minimum of heat loss.

Evaflow, a second type of heated hose, is designed to withstand only a comparatively low fluid pressure and a small degree of flexing. Instead of braided wire conductors, it has two concentric wire coils in the hose walls. **Heated Hoses Ltd., Egerton Lane, Sheffield, 1.**

BCE 8037 for further information

Reinforced Plastics Pipes

Being shown for the first time recently at the International Pipes and Pipelines Exhibition in London was the new Bristol Pipe, a range of reinforced epoxy resin piping now being produced by Bristol Aeroplane Plastics Ltd.

It is a complete pressure piping system of thermosetting epoxide resin reinforced with high-strength glass fibres, and is produced in sizes ranging from 6 in. to 15¼ in. bore. Piping is supplied in standard 20-ft lengths, with a standard range of ancillary fittings, tees, bends and flanges. The pipes can be either flange-jointed or bonded: the bonded-joint method is said to be favoured for permanent pipeline installations, and Bristol has developed special mobile equipment enabling pipes

to be rapidly bonded *in situ*.

Bristol Pipe is highly resistant to corrosion and is virtually unaffected by soils, sea-water, demineralised water and the majority of dilute acids and alkalis, even up to temperatures of 120°C. As the epoxide resin glass filament structure is also a non-conductor of electricity and not subject to electrolytic action, pipes can be safely buried in the ground without any form of corrosion protective coating or cathodic protection. The freedom from corrosion defects and build-up of wax deposits on the smooth interior ensures low friction losses and minimum pumping costs.

Because of its low weight, it is said that with the mobile bonding unit three men can lay up to 200 ft/hr of 6-in. diameter bonded pipeline. **Bristol Aeroplane Plastics Ltd., Filton House, Bristol.**

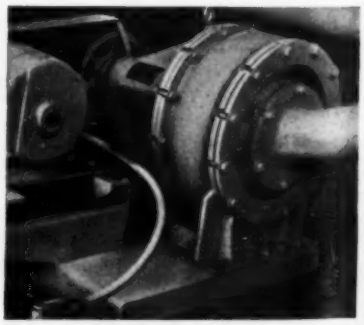
BCE 8038 for further information

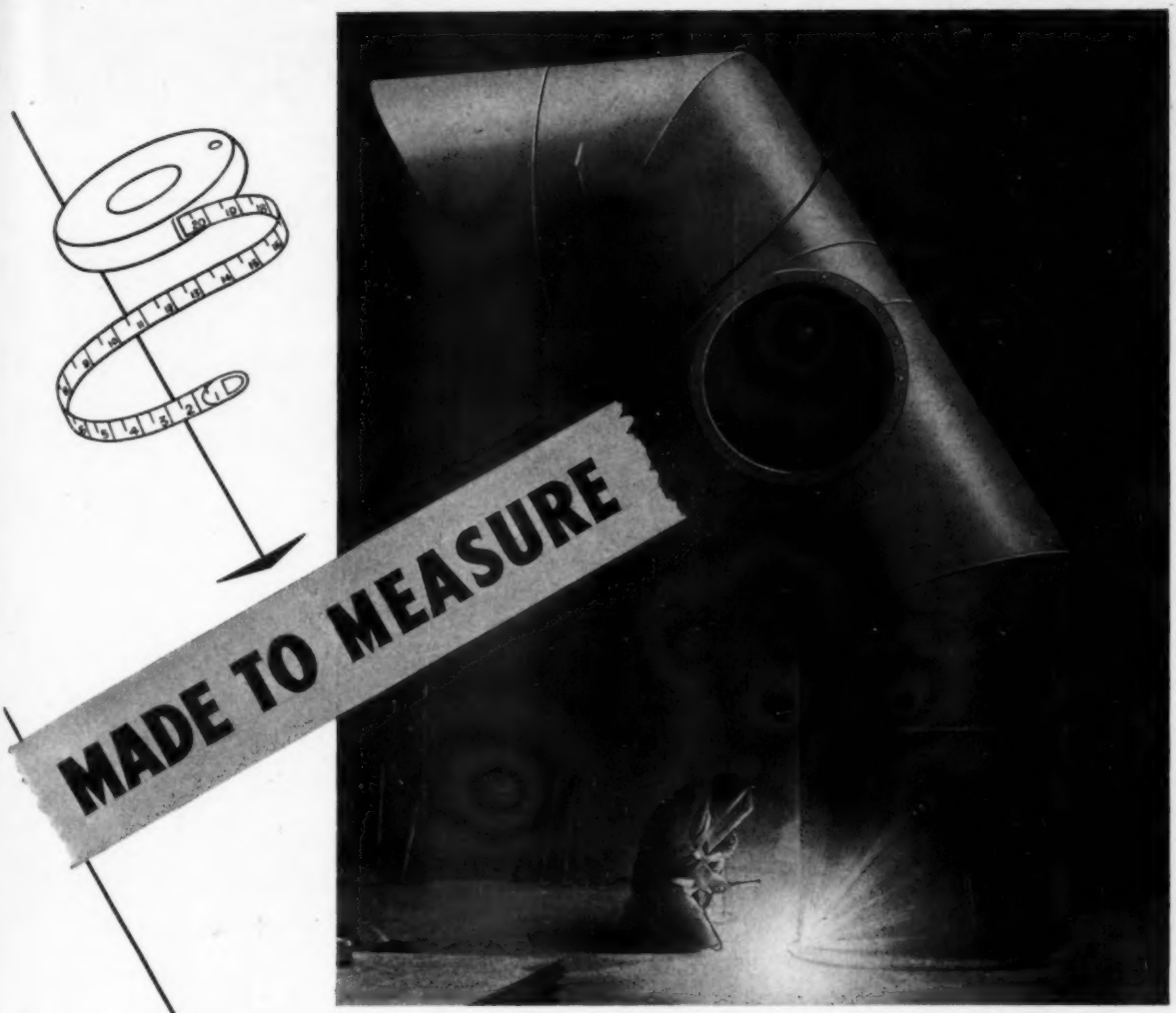
Torque Flow Pump

A variety of difficult materials can be handled by the new Scott-Wemco Torque-Flow pump, according to the manufacturers, George Scott & Son (London) Ltd., one of the Balfour Group. The principle of the pump is in a recessed impeller, located completely out of the flow pattern, which imparts a swirling action to the material in transit, causing suction and discharge to become one continuous open passage from inlet to exit flanges.

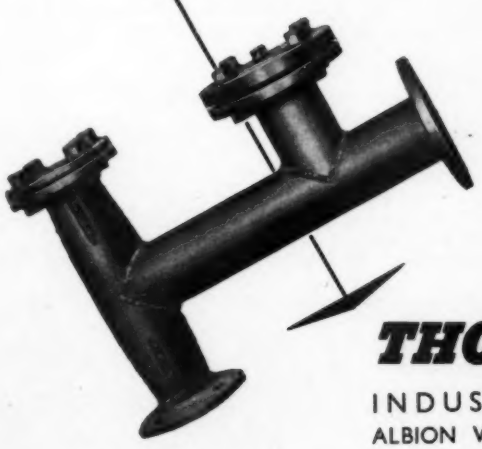
Particles and solids are drawn into the swirling vortex and discharged with a centrifugal sweep from the open chamber, seldom even touching the impeller.

The pump is claimed to be highly effective or a wide range of materials, sludges and slurries of high solids content, tough abrasives, soft, sticky or fibrous materials all being handled without trouble. It can also deal with comparatively fragile substances because





DUCT & PIPEWORK



Every installation by Wards, large or small, intricate or straightforward, is the result of careful planning by experts. The final system, for steam, air, or water, is the best and the most economic solution to whatever pipework problem is presented.

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PLANT EQUIPMENT NEWS

there are no violent directional changes or confined passages in the flow area.

Minimum maintenance is a special feature. Field tests have been made with effluents containing rags, ropes, hair, rubber, wire and stones, without causing blockages or necessitating frequent stripping down.

Paper and wood pulp, crushed bones and shredded hides for the gelatine industry, coal slurries, sand, gravel and minerals, all in the form of suspensions, can be handled without any reported difficulty. An important feature is in the handling of crystalline slurries where there is little or no degradation of the crystals, since the impeller seldom touches the material being pumped. **George Scott & Son (London) Ltd., Levenbank, Leven, Fife.**

BCE 8039 for further information

Air Heater Units

Standard direct gas-fired air heater units now being produced by A. E. Griffiths (Smethwick) Ltd. are designed for use for low-temperature ovens, drying rooms, curing chambers and many similar applications. Adaptable for use where an air temperature up to a maximum of 300°F is suitable, they are made in a range of four models with an air delivery rate of from 455 to 4500 cfm.

Basically, the units comprise a filtered air inlet through which an air supply passes around the gas burner and then to a fan from which suitable ductwork connections may be made on site to whatever plant is required. Each unit incorporates a secondary connection for return air to be recirculated.

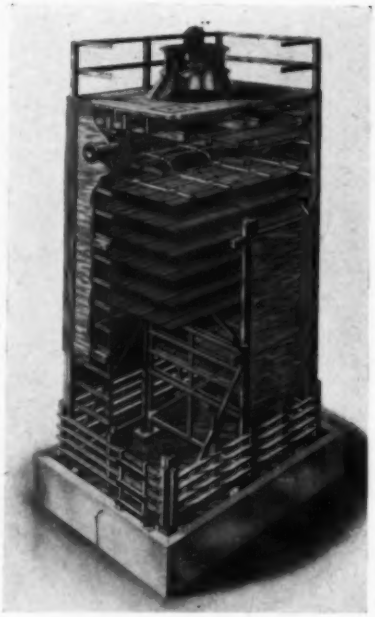
A relay type thermostat control is incorporated for operation on high/low flame. A gas pressure governor is also provided to ensure constant gas pressure conditions. **A. E. Griffiths (Smethwick) Ltd., Booth Street, Birmingham, 21.**

BCE 8040 for further information

Cooling Tower

Known as the type D, the new cooling tower just announced by Foster Wheeler Ltd. is an induced draught tower designed to cool water quantities between 50 and 1500 Imp gal/min. Constructed of treated timber and completely fabricated, the unit is delivered to site in sections for simple erection, all sections being bolted together.

The tower consists of a series of standard units with a cross-sectional area ranging from 6 × 6 ft to 16 × 16 ft. A two-course chevron-type eliminator is installed above the distribution system to prevent air-entrained droplets of water from being carried by the discharge air stream to atmosphere. The distribution system itself comprises an open timber trough and lateral pipes which direct the water flow on to splash cups, which are spaced so as to give uniform water distribution over the tower area. Fill racks (which are easily removable) are designed



to break the fall of water into multiple cascade effects, and offer minimum resistance to air flow. Removable louvre boards prevent splash from the bottom of the tower, and can be easily removed for access. In winter conditions, louvres may be set vertically to retard the formation of ice.

A waterproof motor drives the fan, both of which are mounted centrally in a fan ring.

The design of the tower allows for a 30 lb./sq. ft wind load, making is possible for these units to be located if necessary on the roof of a suitable building. The water-collecting basin forming the foundation can be constructed of concrete, steel or other suitable material.

For cooling duties greater than those for which the type D is designed, the company produces the type C tower. This is also of the splash type, and is designed to ensure even distribution of air and water flow over the whole cross-sectional area of the unit. The fan is driven through a floating shaft and gearbox by a motor located on the top deck outside the fan ring. These towers can be constructed entirely of timber or reinforced concrete, with timber, timber and asbestos or concrete casings. **Foster Wheeler Ltd., Foster Wheeler House, 3 Ixworth Place, London, S.W.3.**

BCE 8041 for further information

Heat Exchangers

Execptionally high heat-transfer rates are claimed for the Rosenblad plate heat exchangers which are now being marketed in the U.K. by British Boiler Accessories Ltd. Part manufacture of the units is expected to be started soon in this country.

Distinctive feature of the unit is its plate design which is a herringbone shape, which enables high pressures up to 210 psi to be used on the standard unit, and makes possible a high heat-transfer coefficient.

Designed particularly for use in the chemical and general manufacturing industries, it is available in various forms and consists essentially of two parts, between which the gasketed, corrugated plates are compressed to seal the assembly. Inlet and outlet nozzles for the fluids are fixed to the frame. The herringbone-pattern plates in the heat-transfer area are arranged so that the corrugations on adjacent plates cross at a very large number of uniformly distributed points, thus offering advantages for both strength and heat transfer.

A valuable feature is in the method of plate suspension: each plate is equipped with a simple, detachable suspension member which can be slipped on or off in a matter of seconds without the use of tools.

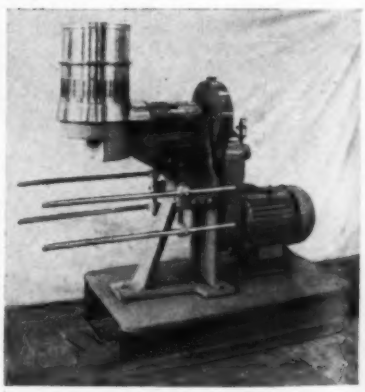
Moulded gaskets are of a composition suitable for the particular service conditions. They are cemented to each plate to prevent damage when assembling and dismantling. The gasket channels are designed to prevent the gasket being blown out; auxiliary corrugations and bosses are formed in the plate to give full support to both sides of all gaskets.

The heat exchangers can be supplied in most materials including stainless steel, Monel, titanium and hard lead. **British Boiler Accessories Ltd., 62/3 Fenchurch Street, London, E.C.3.**

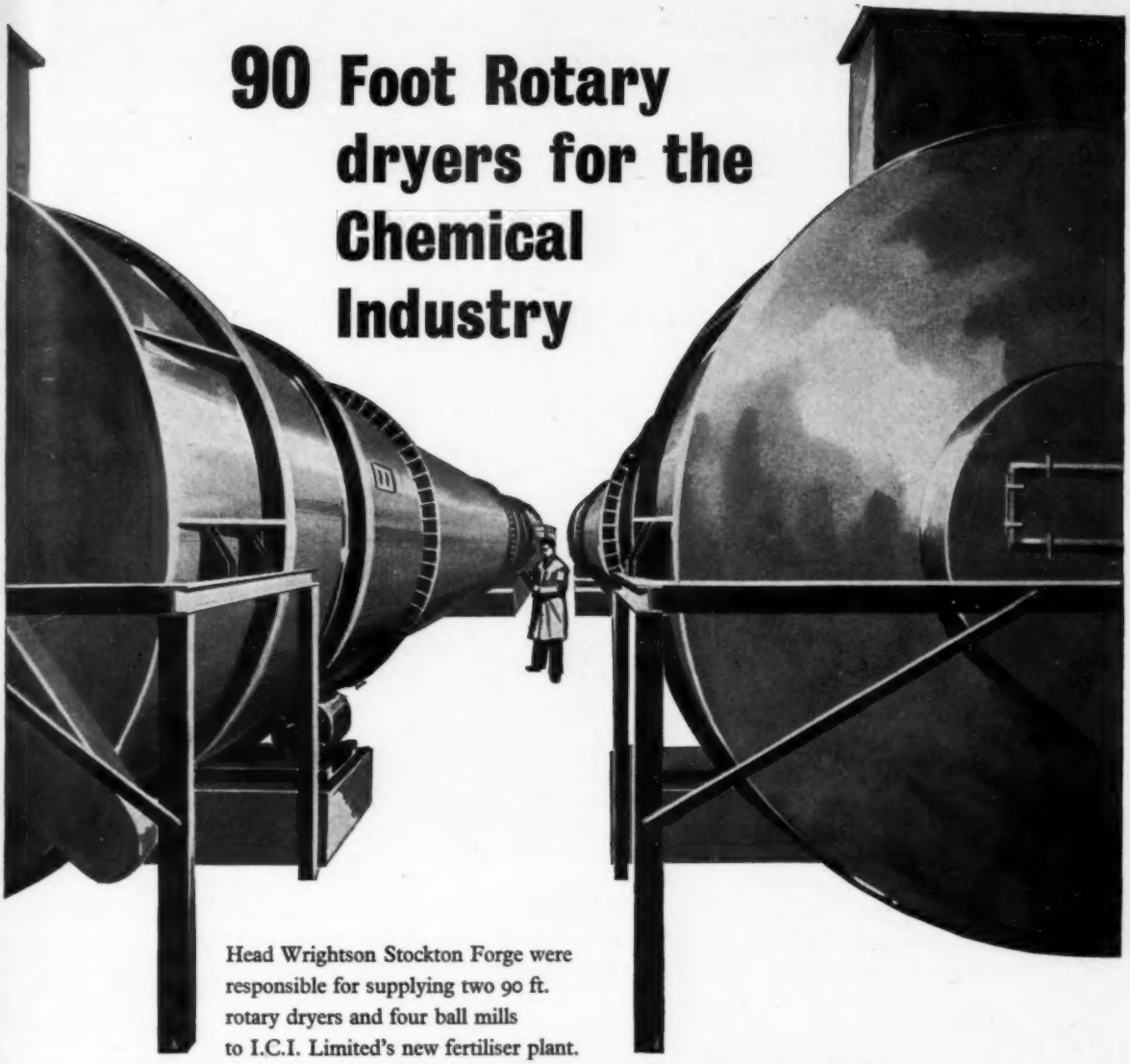
BCE 8042 for further information

Rotary Wet Granulators

Over the last few years granulation has become a process of increasing importance and many new machines have been designed to meet the growing demands of industry. One important contribution to granulating techniques has been the comminuting mill which, due to its great flexibility, has enabled new granular products to be produced and has increased productivity. Every type of machine has its limitations, and where formulations contain a high percentage of sugar or other soluble material, such as extracts, granulation is difficult to obtain as the product tends to adhere to the machine and blind the screen. A new rotary wet



90 Foot Rotary dryers for the Chemical Industry



Head Wrightson Stockton Forge were responsible for supplying two 90 ft. rotary dryers and four ball mills to I.C.I. Limited's new fertiliser plant. The dryers are among the largest machines of this type ever to be built.

Head Wrightson have specialised in the design and manufacture of drying and grinding equipment for the Chemical and Mining industries for many years and have installed similar equipment in many plants in this country and abroad.

Please write for further information or telephone Stockton 65268.

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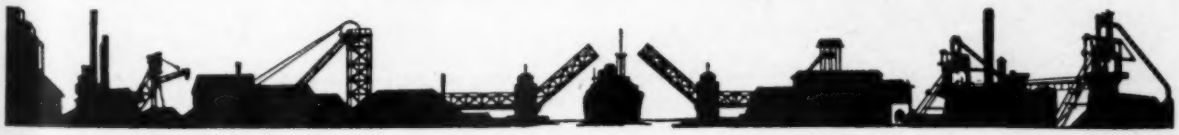


PLANT EQUIPMENT NEWS

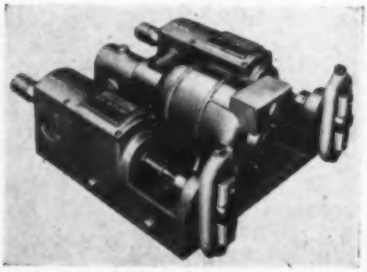
granulator has been designed to handle these sticky or waxy materials and will usually produce firmer and stronger granules than those produced by any other method, as well as giving high production throughout. This granulator will also handle plastic materials including those of a waxy nature. Apart from its wide use in the pharmaceutical industry, this granulator has been successfully applied in the food industry for the manufacture of products in granulated form. The No. 52R granulator produces granules by extruding material through a vertical perforated screen. The screens are fitted in the bottom portion of a stainless-steel hopper which is in two halves, the lower half of which has square windows. The screens are easily interchangeable and are available with holes from 3/64 in. up to ¼ in. diameter. The material is pressed through the perforated screen by means of a multi-armed spreader, the material being fed to the spreader by means of a feeder arm. A stainless-steel shroud is fitted over the cast-iron housing below the screen to discharge the granules, and tray supports are fitted to the granulator so that the granules can be collected on trays for drying. The spreader and the feeder are rotated on a vertical shaft in opposite directions. All parts in contact with the material are in stainless steel or Monel metal. The No. 52 granulators are self-contained units complete with motor drive and are available in two sizes. The smaller size has an output based on sugar of 300 lb/hr, whilst the larger size has an output of 1800 lb/hr. **Apex Construction Ltd., 15 Soho Square, London, W.1.**

BCE 8043 for further information

Metering Pumps

The range of the Distillers Co.'s metering pumps has recently been further extended by the development of a duplex version of the type M pump. By embodying in the new version two of the type M standard pumping heads driven 180 deg. out of phase from a common motor, the output of the motor is said to be doubled and the flow characteristics are improved when the heads are operated in parallel. Alternatively, each head can be operated as an independent metering head pumping two different liquids.

The duplex pump is designed to accommodate automatic control on both or one of the pump heads. It is available with totally-enclosed or flameproof motors and will also accommodate 60 c/s motors by modified gearing.



Maximum capacity of each cylinder is 8.23 gph at 50 psig with a series of alternative pump heads giving infinitely variable ranges of capacity for smaller volumes and higher pressures. **The Distillers Co. Ltd., Great Burgh, Epsom, Surrey.**

BCE 8044 for further information

Furnace

The G.W.B.-Vekos stoker, which is claimed to be based on entirely new principles, is basically a self-contained pre-burning unit. It is automatically controlled and fed, and it is said that it will burn all types of bituminous fuels, including even strongly-caking coal.

The stoker can be fitted to almost any type of fire-tube or water-tube boiler, and is designed to add to the boiler efficiency, as well as to its capacity. The automatic control of the fuel supply and the combustion air ensures a constant fuel/air ratio, providing a high CO_2 value of 14-16% with smoke-free operation. **G.W.B. Furnaces Ltd., P.O. Box No. 4, Dibdale Works, Dudley, Worcs.**

BCE 8045 for further information

New Publications

Flexibox mechanical seals for rotary shafts are now very well known throughout industry, although the first seal of this type was produced only 15 years ago. A booklet just issued by Flexibox Ltd. describes the complete range of seals now available and the various special arrangements that are possible with the equipment. At the end of the book there is a very useful table which enables the recommended seal component material for a particular liquid to be ascertained at a glance. **Flexibox Ltd., Nash Road, Trafford Park, Manchester, 17.**

BCE 8046 for further information

Zirconium is the subject of one of the latest booklets to come from the Metals Division of Imperial Chemical Industries Ltd. The publication traces the history of zirconium and describes the uses of the material and its alloys. The main applications for the material are in the nuclear field and these are fully discussed. In addition, however, I.C.I. Zirconium 10 and 15 have been successfully used for lined vessels, pump and valve components, agitators and other items of chemical plant. **Imperial Chemical Industries Ltd., P.O. Box 216, Birmingham, 6.**

BCE 8047 for further information

A 28-page booklet published by Head Wrightson Stockton Forge Ltd. describes the company's range of Ruggles-Coles driers, of which there are now seven types available. In addition, Ruggles-Coles rotary kilns and coolers are discussed briefly at the end of the publication. The booklet discusses the fundamentals of drying and gives very full details about the construction and applications of this plant. **Head Wrightson Stockton Forge Ltd., Stockton Forge Works, Stockton-on-Tees.**

BCE 8048 for further information

The properties and applications of SG iron are described very fully in a 38-page booklet published by the Mond Nickel Co. Ltd. The material, which is also known as nodular and ductile iron, has a high modulus of elasticity and excellent resistance to corrosion and wear. There are five basic types of SG iron—pearlitic, hardened, ferritic, alloyed and austenitic. The iron has a number of applications in the chemical industry, all of which are listed. **Mond Nickel Co. Ltd., Thames House, Millbank, London, S.W.1.**

BCE 8049 for further information

A 16-page booklet describes in detail the Technicon Autoanalyzer. This equipment comprises a series of modules which, by continuous chemical analysis, gives continuous control of product composition. Plant control is achieved by fitting switches, slide-wires, or pneumatic pilots to the recorder, which can also feed digital computers, punched-card systems, etc. An important feature of the Autoanalyzer is that it can isolate constituents in process-streams, thus affording quality-control during production and not after. The Autoanalyzer makes complete water-analysis data immediately available on a continuous basis. **Technicon Instruments Co. Ltd., 26 Warwick Road, London, S.W.5.**

BCE 8050 for further information

In a booklet just issued by P.G. Engineering Ltd., brief details are given of the company's chemical, gas and petroleum plant divisions and the general contract division. The company designs and erects complete plants for the chemical, petroleum, gas, nuclear energy, and iron and steel industries. A central service of the Power Gas Group is available to assist each of the company's four groups. The booklet is printed in four languages—English, French, Spanish and German. **P.G. Engineering Ltd., Parkfield Works, Stockton-on-Tees.**

BCE 8051 for further information

A booklet issued by Expanded Rubber Co. Ltd. describes how Onazote, a form of expanded ebonite, may be used for the low-temperature insulation of pipelines and storage vessels. Called "Onazote for Pipelines and Storage Vessels", the booklet gives details of the thickness of Onazote needed on various pipe diameters, in comparison with cork, and comparative heat transmission of the two materials. One of Onazote's most important qualities is its low conductivity—said to be the lowest of any known rigid insulant. Its established "K" figure is 0.20 Btu/sq. ft/h/F°/in. at a mean temperature of 50°F. **Expanded Rubber Co. Ltd., Mitcham Road, Croydon, Surrey.**

BCE 8052 for further information

BCE 7999 for further information

BRISTOL PIPE

Bristol Plastics have developed a range of high-precision pipes which has a wide variety of heavy-duty applications. Wherever problems of corrosion or weight interfere with efficient pumping or installation, Bristol pipes offer many big advantages over conventional steel piping.

Bristol Pipe Construction

Bristol pipes are made up of immensely strong helical windings of glass cords embedded in epoxide resin and lined with an abrasion-resistant synthetic fibre matrix which has a glass-smooth surface. Bristol pipes can be manufactured at present in any size from a 6-inch to a 15¼-inch bore, and production techniques are being developed to increase the available bore diameters to 3 feet.

Bristol Pipe Properties

Bristol pipes are highly resistant to corrosion. They need no protective sheathing and can handle liquids, including dilute acids and other corrosive chemicals at high pressures up to 600 psi and above, and up to 140° C.

Bristol pipes are *only one quarter the weight of steel* yet they have the same tensile strength as steel piping and can withstand the same degree of abrasion. Being very light, they can be assembled in prefabricated sections which require no special handling equipment. In fact, three men, using Bristol patented couplings, can install or lay 200 ft of 6-inch pressure pipe per hour!

Bristol Pipe patented couplings.

As the pipe bore is glass smooth, flow characteristics are extremely good. And this means that less pumping equipment and smaller-diameter pipes can be used for the same bulk flow.

Bristol Pipe Applications

Bristol pipes have been specially designed for conditions where steel piping corrodes, where installation costs are high, or where prefabricated systems can be used to advantage. Bristol pipes are particularly suitable for chemical plants, oil-well installations and natural-gas pumping stations, and for many other similar applications.

Enquiries should be addressed to:—**Sales Department, Bristol Aeroplane Plastics Limited, Filton, Bristol, England.**

A PRODUCT OF

BRISTOL

AEROPLANE PLASTICS LIMITED

PLANT EQUIPMENT NEWS

Four new leaflets issued by Baker Perkins Ltd. describe heat-transfer equipment and continuous mixers. One of the brochures gives details of the Rotofeed machine, for continuous mixing, which is made in three standard sizes and has an overall capacity range of a few pounds up to 10 tons per hr. Two of the publications describe various models of the Reactor; This equipment was first produced to cool greases through an accurate time/temperature cycle calling for high rates of heat transfer but has now found a very large range of applications. The fourth leaflet gives details of four items of plant, the continuous universal mixer, continuous semplex mixer, the Reactor and the Rotofeed. **Baker Perkins Ltd., Westwood Works, Peterborough.**

BCE 8053 for further information

Two catalogues have recently been published by Turner Brothers Asbestos Co. Ltd.; both describe the company's belting products. Catalogue BA 73 deals with conveyor belting, and gives details of the vast range of natural and synthetic fibre, rubber-covered, conveyor belts which are available. In addition, much information is given about conveyor belt installation, operation and maintenance. The second publication (BPV.3) describes Poly-V drives and gives engineering data on service factors, horsepower ratings, pulleys and installation, and maintenance instructions. **Turner Brothers Asbestos Co. Ltd., P.O. Box 40, Rochdale, Lancs.**

BCE 8054 for further information

Everyman's Guide to PVC Plastics is the apt sub-title of a booklet issued by British Geon Ltd. Called "The Geon Story", it describes, principally by means of captioned illustrations, the very wide range of applications which this material has now found in industry and the home. **British Geon Ltd., Devonshire House, Piccadilly, London, W.1.**

BCE 8055 for further information

An eight-page booklet issued by Stockdale Engineering Ltd. describes and illustrates U.K. mixers with right-angle drives. The range of powers and speeds given by the standard unit are shown in the form of a coloured table and detailed dimensions are also printed. Three basic types of impellers, the flat back-swept open turbine, marine, and flat-blade turbine are also described and illustrated. **Stockdale Engineering Ltd., Poynton, Cheshire.**

BCE 8056 for further information

In a strong board covering, Kestners have published a 44-page brochure giving a brief review of the company's principal activities and the type of equipment and processes in which they specialise. There are no detailed descriptions, since the intention is to invite the inquirer to send for a separate catalogue if required. The chapters cover crystallising and drying plant, evaporators and heat exchangers, fluid handling and laboratory and pilot plant, materials of construction, metal pickling and processing, process heating and special process plants. There are various indexes. **Kestner Evaporator & Engineering Co. Ltd., Grosvenor Gardens, London, S.W.1.**

BCE 8057 for further information

"Hydraulic Oils" is the title of a 74-page handbook just published by Wakefield-Dick Industrial Oils Ltd., a member of the Castrol Group of Companies. This book, which contains 50 illustrations, will be a most useful addition to the bookshelf of any engineer concerned with the design, installation, operation or maintenance of hydraulic equipment. Students, too, should find the many graphs and formulæ extremely helpful. The book includes chapters on fundamental hydraulic principles; hydraulic systems, pumps and components; and hydraulic fluids. Copies of "Hydraulic Oils" are available to readers of this journal, free on request, to **Wakefield-Dick Industrial Oils Ltd., Castrol House, Marylebone Road, London, N.W.1.**

BCE 8058 for further information

Technical Booklet No. E4, issued by British Resin Products Ltd., gives details of Epok PVA emulsions and their applications. These emulsions are used principally in the production of emulsion paints, but they also have applications for adhesives, paper making, carpet manufacture, flooring compositions, textiles and glassfibre products. **British Resin Products Ltd., Devonshire House, Piccadilly, London, W.1.**

BCE 8059 for further information

Entitled "The Work We Do", a brochure issued by the Birmingham & Blackburn Construction Co. Ltd. surveys the products made by the company. These include sheet metalwork, fabricated platework and constructional steelwork. There is also a section on general engineering. Installation of heating and ventilating equipment is another facet of the company's activities and details of these are given towards the end of the publication. **The Birmingham & Blackburn Construction Co. Ltd., Armoury Close, Bordesley Green, Birmingham.**

BCE 8060 for further information

A catalogue recently produced by Fischer & Porter Ltd. describes the company's range of indicating variable and flow meters, sold under the name of Flowrators. The publication describes in detail all the models in the range, and the basic Flowrator theory is also discussed. In addition, complete flow calibration curves and conversion formulæ are given which enables the flow of any fluid through any type of Flowrator to be determined. The use of standard scaling enables instruments and spares to be listed in a stock system, thus reducing complexities when ordering. **Fischer & Porter Ltd., Salterbeck Trading Estate, Workington, Cumberland.**

BCE 8061 for further information

A very well produced and illustrated booklet entitled "A Service to Industry" traces the progress of Ashmore, Benson, Pease & Co. Ltd. throughout the last 10 years. The company, which was founded in 1873, is an engineering organisation offering a comprehensive service to heavy industries throughout the world. Most of the publication is taken up with descriptions of the manufacturing facilities of the company, and there are also sections describing design facilities, site erection, transportation and blast furnace equipment in use. **Ashmore Benson, Pease & Co. Ltd., P.O. Box 17, Stockton-on-Tees.**

BCE 8062 for further information

Camrex non-oxidising preservative is described in a book published by Camrex Paints Ltd. First produced some 50 years ago, Camrex N.O.P. is now widely used in the coal, chemical, steel, plating and metal finishing, electrical, gas, cabonisation and galvanising industries. The properties of the coating, of which several grades are made, are discussed briefly and a number of testimonials from users are printed. **Camrex Paints Ltd., Sunderland.**

BCE 8063 for further information

A brochure published by Tough Plastics Ltd. describes the qualities of Tufplas, a laminated material consisting of an inner surface of completely unplasticised p.v.c., and an outer surface of polyester resin reinforced by glass fibre. The two layers are chemically bonded by a new process. Tufplas has been designed for use in fabricating tanks used for storing or processing liquid which attack steel vessels. It is also suitable for ventilation or fume extraction systems, pipes and pipelines. The brochure also lists the extensive stocks of unplasticised p.v.c. materials held by the company. **Tough Plastics Ltd., Wey Lock Works, Byfleet Road, New Haw, Weybridge, Surrey.**

BCE 8064 for further information

A new colour brochure published by Burnett & Lewis Ltd. describes and illustrates the company's standard fully-automatic Humidryers designed for chemical engineering, petroleum and other engineering applications. Two principal types are available. The type PR Humidryer is intended for drying moderate flows of compressed air and gases of up to 230 psig at rates of up to 300 scfm. Although intended principally for drying compressed air to supply pneumatic control instruments, valves and other air-operated tools and equipment, it can be also used to dry gases such as nitrogen, CO_2 and hydrogen, etc. It is built in a range of four standard models. The type DS and DSR driers are built in several sizes for drying flows of compressed air and gases up to 5000 scfm at operating pressures up to 150 psig. Models for other duties and special requirements can be made as required. **Burnett & Lewis Ltd., Redhouse Industrial Estate, Aldridge, Walsall, Staffs.**

BCE 8065 for further information

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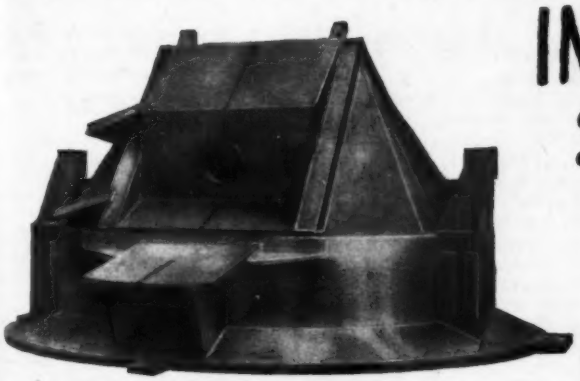

Illustration shows an intricate sub-assembly in Aluminium Alloy, material specification: N6 (5·5 mag) Fabricated in 1¼, ⅜, ½ and ¼ inch thick material. Diameter 6 ft. Welded by Argon-aut (Consumable wire process)

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Continuous vertical retort structure and supporting steelwork, at Lostock Hall Works, Preston; Denso protected by The Denso Contracting Department. Photograph by courtesy of The North Western Gas Board.

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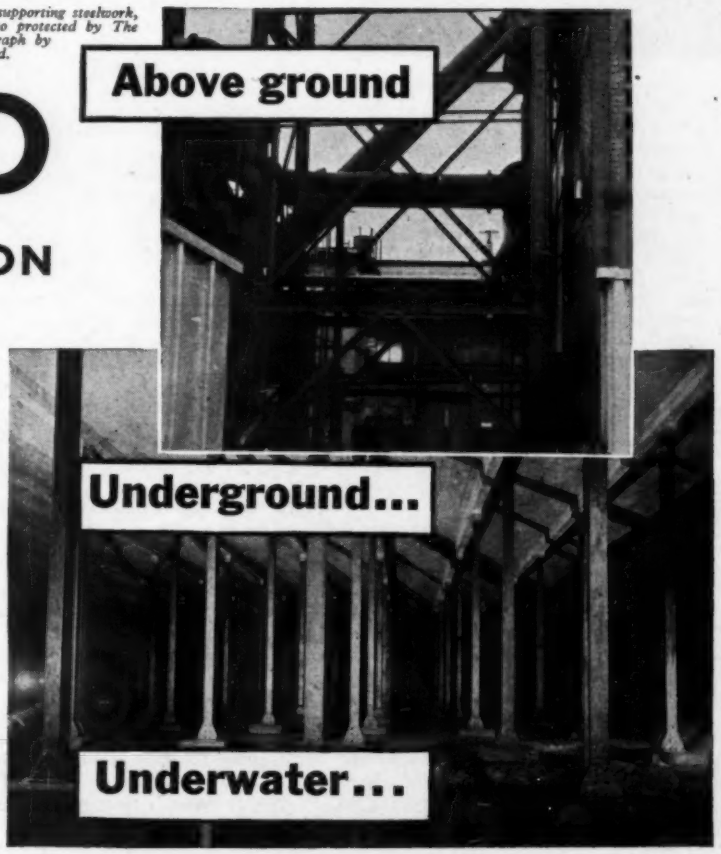

Roof stanchions and other steelwork in this main reservoir Denso protected by The Denso Contracting Department. Photograph by courtesy of Widnes Corporation Waterworks.

BCE 8001 for further information

World of Chemical Engineering

New Carbide Plant

The new Carbide Industries plant at Maydown, near Londonderry, for producing calcium carbide and acetylene was officially opened recently by Lord Chandos, chairman of the Northern Ireland Development Council. The plant, much of which was designed and built by British Oxygen Engineering Ltd., is the first acetylene and carbide plant to be built in Northern Ireland, and it is exceptional in being the first tonnage acetylene plant to be built in the United Kingdom; initially, the main outlet for the gas will be in the manufacture of neoprene to be carried out at the neighbouring du Pont plant.

The new carbide factory at Maydown.

The heart of the process is the electrothermal reduction furnace, supplied by Norske Electrokemisk A/S of Oslo. It is a totally enclosed furnace of the rotating type and the outstanding feature is collection and scrubbing gases and their subsequent use to supply heat to the Priest kilns. The calorific value of the gas is approximately 300 Btu/cu. ft and the quantity withdrawn from the furnace is almost, but not quite, enough to provide the heat required by the kilns. Make-up gas and gas for starting-up is provided by Humphreys & Glasgow gas producers.

Compared with other plants employing open furnaces, the results of closed operation are impressive, for not only was the plant commendably clean, but dust emission was completely eliminated.

Other interesting points were the use of hot waste gases from the lime kilns (temperatures approximately 350°C) for drying the coke in a Roto-Louvre drier (Dunford & Elliott); again various parts of the furnace, particularly its top, are water-cooled and as much as 100,000 gph are circulated for this purpose. This water is cooled in induced-draught towers, an interesting feature being that the feed to the towers is by gravity from the furnace.

The site occupies 60 acres, but so far no more than half this area has been developed. It was noticeable that the plant had been designed to allow ready expansion.

Congress in Mexico City

No less than 83 papers covering an exceptionally wide range of chemical engineering topics were presented at the recent conference held in Mexico City towards the end of June. This event, jointly organised by the A.I.Ch.E. and the Mexican Institute of Chemical Engineering, included among its activities visits to a number of plants, some of them with features of considerable interest. Such a visit was to one of the first heavy chemical plants to be set up in Mexico, the Sosa Texcoco S.A. Factory, whose major products are caustic soda and soda ash. The raw material supply for this plant is the alkaline brine from the partially dried-up Texcoco Lake; this brine is made up of equivalent quantities of sodium chloride and sodium carbonate totalling 100 million U.S. tons. Of particular interest to the visitors was the spiral-shaped solar evaporator "El Caraco", which concentrates the brine from the lake to a 12% total alkalinity, the brine taking around a year to pass through the complete spiral of the evaporator, the water evaporation rate during the dry season exceeding 2 million cu. ft per day. Other sections of this plant which the visitors were able to examine closely included the modern multiple-effect evaporators, carbonating towers and brine burning facilities. Outputs at present amount to 250 and 100 tpd of sodium carbonate and caustic soda respectively, but a projected expansion is expected to increase the soda ash production to 500 tpd.

Another plant included in the round of visits was the paper mill of Cia Industrial De San Cristobal S.A., a plant reputed to be the most advanced in the world for the manufacture of pulp and paper from sugar-cane bagasse. Indeed, the main point of attraction proved to be the unique process carried on at this plant for converting the bagasse fibres to a pulp comparable in quality to that produced from wood.

Mexican Petrochemicals Launched

Another visit was to the Atzcapotzalco refinery of Petroleos Mexicanos, Mexico City. This plant refines 10,000 bpd of medium and heavy crudes and produces 30,000 bpd of automobile and aviation fuel. There is installed here the first Mexican fluid cat-cracker, which so far has been in operation for two years.

Among the new units which the visitors were able to inspect was the HF alkylate plant which has a capacity of 3000 bpd of alkylate, and, most noteworthy, what is believed to be the largest successful viscosity breaking operation in the world. It processes 25,000 bpd of heavy asphalt and converts it to bunker fuel.

Also in evidence were preparations for the initiation of a Mexican petrochemical industry. Two steps of the programme are now in operation, one being a sulphur recovery plant and the other the unit for the manufacture of 45 tpd of dodecylbenzene.

Papers Cover Wide Field

As was to be expected, the subjects treated in the papers represented a very broad field. One symposium, for example, was devoted to those aspects of technology of particular significance to Mexican industry, the subjects of this group ranging from national gas processing developments (G. E. Webber and I. Walke), the Mexican national gas industries (Mario Rojas) and the future of refining in Latin America (S. W. Carry and E. W. Schnable). In the sphere of cost estimation, a subject which received a great deal of attention at the congress, the papers presented dealt with construction and operating costs from both the Mexican and U.S. viewpoints, the estimating of manufacturing and construction costs, and a comparison of manufacturing and construction costs in Latin America with those in other parts of the world.

An unusual topic in this group of papers was the odorising of L.P.G., which was considered from the aspects of safety, economy and technology. Indeed, the technological problems of odorising L.P.G. in the liquid and gaseous phases were discussed from the thermodynamic angle (I. B. Calva).

Education, machine computation and process optimisation distillation, cryogenic engineering and transfer processes in two-phase systems were other fields covered by the several symposia and, in addition, a number of sessions were devoted to selected papers, some of which presented new physical and kinetic data, whereas others were concerned with design methods and new types of equipment.

Entrainment in Distillation Columns

In the distillation field, I. A. C. Isaacs performed the all-too-rare function of comparing actual and estimated performances of a plant unit, in this instance a de-iso-butane bubble-cap tower in which iso-butane was present. The observed plate efficiencies proved to be higher than those predicted by existing design formulæ. In the same field, a group of M. W. Kellogg engineers (L. Friend, E. G. Lemieuse and W. C. Schreiner) presented a paper on entrainment from closely spaced perforated trays. In the work described, carried out with holes of from $\frac{3}{16}$-$\frac{1}{4}$ in. diameter, and with free areas varying from 8-12%, entrainment increased with increasing hole size, weir height, vapour velocity and liquid rate, and diminished with increased tray spacing. In another sieve tray paper S. I. Cheng and A. S. Teller produced an

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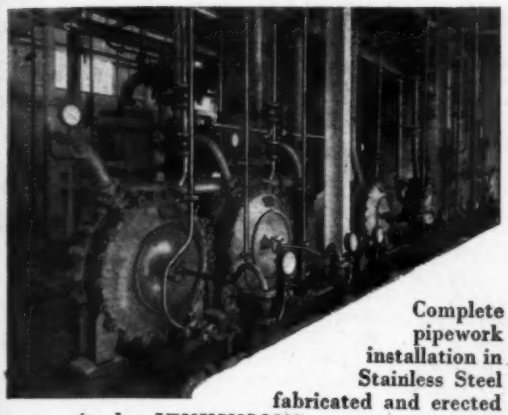

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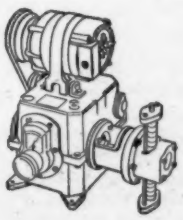

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expression relating the amount of entrainment with height above foam level, which was shown to give results in good agreement with practice.

Plate Efficiencies

Yet another distillation paper (A. Matesanz) reported plate efficiencies and the results of direct visual observations of the distillation conditions for O_2-N_2-Ar_2 mixtures. In this work an interesting feature was the automatic control of nitrogen liquid level by a thermistor. Subjects of papers with a strong design interest included a method for estimating minimum reflux ratios in the rectification of multi-component mixtures (K. Green), the efficiency of rotary drum filters (H. R. Cooper), the solution of heat-transfer problems by hydraulic analogue computer (Carlos Duhne) including regenerator calculations (Carlos Duhne and H. C. Garcia), and equations for the heat transfer of pseudo-plastic fluids in laminar flow (E. B. Christiansen).

Studies of fluid flow and mass transfer in trickle bed reactors was the subject of another paper in this field (W. N. Schiesser and L. Lapidus) which reported on the residence-time behaviour of a liquid flowing through a reactor of this kind. It was shown that in the case of non-porous packing pronounced radial variation in the fluid velocity occurs if the ratio of tube to particle diameter is less than 16:1. In the case of porous packing it is shown that the hydro-dynamic and diffusional properties can be recognised separately.

A number of papers were also presented with a marked chemical engineering science bias. Of these, one of the most outstanding was given jointly by R. L. Pigford and S. Whitaker, who described the effect of subjecting a liquid film to a sinusoidally varying SO_2 pressure.

New Processes

Some new processes also came to light during the congress. One of these included a new type of plant for recovering HCl from inerts. The unit described strips strong HCl from the absorption liquor and uses the stripped weak acid for absorbing HCl from the inert gases. H. L. Ramos described the design and operation of a new type of solid liquid extractor; this contains two vertical columns connected by a base of special design. In one column the solids are dispersed by a number of turbo-impellers spaced at intervals along a vertical shaft, and in the other the solids and liquid are elevated by means of a continuous spiral.

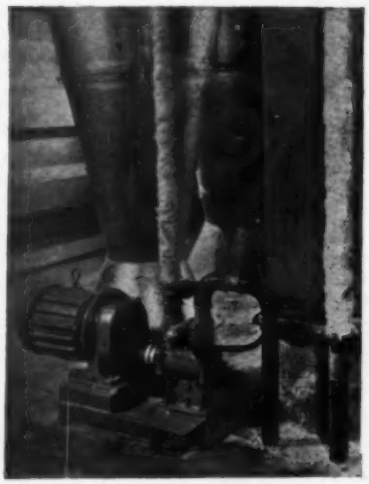
New Process for Niobium

One of the highlights was the announcement of a new process for the reduction of niobium, developed by the Bartelle Memorial Institute for Novabeauceage Mines. By contrast with the electrolytic process for producing niobium which must be carried out batchwise, the new process, which employs the fluidised-bed technique, can be carried out continuously, and is based upon the reduction of niobium pentachloride by hydrogen. In the process the volatile niobium pentachloride is fed into a reactor chamber containing a fluidised bed of seed niobium. Subsequent reduction by the hydrogen fluidising gas at 1500°F produces metallic niobium which is deposited on the seed particles. Seed for the fluidised bed is replenished by grinding a portion of the end-product and recycling it into the reactor.

The product has a quality corresponding to less than 500 parts per million of impurities; the metal is therefore suitable for use in nuclear reactor fuel elements.

A Pumping Problem

A solution to an awkward pumping problem has been reported by Goodyear Pumps, the application being the transference of molasses. The operating conditions are such that the molasses initially have a viscosity of 150,000 seconds Redwood scale, which decreases to 25,000 seconds at 90°F, which represents normal operating conditions; at the start of the operation, the suction pipe is partially full. This particular application is to be found at the Worcestershire Farmers mills and the pump is situated 10 ft below and 30 ft away from the tank containing the liquid molasses. The output of the pump is 90 gph, the quantity required by the mixing plant. The relief valve fitted on the discharge of the pump is set at 87 psi, and the flow is regulated according to the demands of the mixing plant, a shut-off valve being fitted for this purpose.



A rotary pump handling molasses.

Some Recent Articles on Chemical Engineering

Maximum Stable Droplets in Dispersoids
R. A. Mugele
A.I.Ch.E. Journal, 1960, **6**, 1, 3.

Evaporation from Drops Containing Dissolved Solids
D. H. Charlesworth and W. R. Marshall Jr.
A.I.Ch.E. Journal, 1960, **6**, 1, 9.

The Application of Boundary-layer Theory to Power-law Pseudoplastic Fluids: Similar Solutions
W. R. Schowalter
A.I.Ch.E. Journal, 1960, **6**, 1, 24.

Heat and Mass Transfer in Spray Drying
Jan Dlouhy and W. H. Gauvin
A.I.Ch.E. Journal, 1960, **6**, 1, 29.

Effect of Dynamic Surface Tension on Nucleate Boiling Coefficients
P. D. Jontz and J. E. Myers
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Centrifugal Filtration Through Beds of Small Spheres
J. B. Bingeman and Jesse Coates
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Thermal Conductivity of Packed Beds
William Schotte
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Heat Transfer Characteristics of Porous Rocks
Daizo Kunii and J. M. Smith
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The Effects of Superheat and Surface Roughness on Boiling Coefficients
H. M. Kurihara and J. E. Myers
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Flow Patterns in Agitated Vessels
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Density Fluctuations in Fluidised Beds
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George F. Scheele, Edward M. Rosen and Thomas J. Hanratty
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A. P. Buthod and Chi Tien
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Salt Effect in Vapor-liquid Equilibrium, Part II
A. I. Johnson and W. F. Furter
Can. Journal Chem. Eng., 1960, **38**, 3, 78.

On Optimum Cross-current Extraction
R. Aris, D. F. Rudd and N. R. Amundson
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L. E. Scriven
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Two-phase (Gas-liquid) Flow Phenomena I. Pressure Drop and Hold-up for Two-phase Flow in Vertical Tubes
G. H. Anderson and B. G. Mantzouranis
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Froth Flotation: The Adhesion of Solid Particles to Flat Interfaces and Bubbles
C. W. Nutt
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On the Optimum Temperature Pattern in a Reaction Tube
F. Horn and U. Troltenier
Chem.-Ing.-Tech., 1960, **32**, 382.

Heat Transfer and Pressure Drop with Undeveloped Laminar Flow in Pipes and Smooth Channels
A. Schack and K. Stephan
Chem.-Ing.-Tech., 1960, **32**, 394.

Mass Transfer with Partial Condensation of Vapour Mixtures
E. Kirschbaum and E. Troester
Chem.-Ing.-Tech., 1960, **32**, 395.